THE ROLES OF SCENE CHARACTERISTICS, MEMORY AND ATTENTIONAL BREADTH ON THE REPRESENTATION OF COMPLEX REAL-WORLD SCENES

Heather Lynne Pringle, Capt, USAF
Univeristy of Illinois at Urbana-Champaign, 2000
Doctor of Philosophy in Psychology
115 pages

An accurate and detailed representation of the environment is presumed to help observers notice when an object moves or changes. Unfortunately, when change in the environment coincides with an interruption to the ongoing visual processing, observers are surprisingly slow to detect the change, if at all. The factors that play a role in the ability to detect scene changes in the face of interruptions caused by "flicker" are the focus of the research discussed here. Two experiments investigated the roles of intrinsic factors (e.g., attentional breadth, inhibition, perceptual speed, working memory) and extrinsic factors (e.g., change characteristics, scene context) in change detection performance with young and old adults participants. Results indicated that perceptual change detection was best characterized by attentional breadth and visuo-spatial working memory measures. To a lesser extent, perceptual speed was also associated with change detection performance, but the ability to inhibit irrelevant information (i.e., inhibition) had no detectable, independent relationship. Findings also revealed that change meaningfulness had a smaller impact on performance than did salience, especially for the older adults. Examination of eye movements indicated that early in their viewing of the scene, older adults landed on highly meaningful changes that were also of low salience; however, they were not able to explicitly detect the change. Further assessment of eye movements suggested that fixating the change did not ensure detection, rather the duration of processing in the change area increased the likelihood of successfully detecting the change and older adults required longer processing times than younger adults.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	25.May.00	DISSERTATION

4. TITLE AND SUBTITLE
THE ROLES OF SCENE CHARACTERISTICS, MEMORY AND ATTENTIONAL BREATH ON THE REPRESENTATION OF COMPLEX REAL WORLD SCENES

5. FUNDING NUMBERS

6. AUTHOR(S)
CAPT PRINGLE HEATHER L

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UNIVERSITY OF ILLINOIS AT URBANA

8. PERFORMING ORGANIZATION REPORT NUMBER
FY00-177

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited distribution
In Accordance With AFI 35-205/AFIT Sup 1

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

14. SUBJECT TERMS

15. NUMBER OF PAGES
115

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

ABRIDGED LIST OF REFERENCES

Ball, K, Beard, B.L., Roenker, D.L., Miller, R.L. & Griggs, D.S. (1988). Age and visual search: Expanding the useful field of view. Journal of the Optical Society of America, A, 5(12), 2210-2219.

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THESIS

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2000

Urbana, Illinois

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

THE GRADUATE COLLEGE

MAY 2000
(date)

WE HEREBY RECOMMEND THAT THE THESIS BY

HEATHER LYNNE PRINGLE

ENTITLED THE ROLES OF SCENE CHARACTERISTICS, MEMORY AND ATTENTIONAL BREADTH ON THE REPRESENTATION OF COMPLEX REAL-WORLD SCENES

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

THE DEGREE OF DOCTOR OF PHILOSOPHY

Arthur F. Kramer
Director of Thesis Research

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Committee on Final Examination†

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Chairperson

David E. Irwin

† Required for doctor's degree but not for master's.

O-517

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Arthur F. Kramer, Advisor

An accurate and detailed representation of the environment is presumed to help observers notice when an object moves or when an object changes (e.g., drivers should be aware of the details concerning traffic, so that if a car suddenly stops in front of them, they may respond in a timely and appropriate manner by slamming on the brakes). Unfortunately, research has demonstrated that when change in the environment coincides with an interruption to the ongoing visual processing, observers are surprisingly slow to detect the change, if it is detected at all. This "change blindness" suggests that observers lack a sufficiently detailed representation that is robust enough to survive the interruption. The factors that play a role in the ability to detect scene changes in the face of interruptions caused by "flicker" are the focus of the research discussed here. Experiment 1 investigated the role of attentional breadth and change characteristics in perceptual change detection performance. Experiment 2 expanded the objectives in Experiment 1, by additionally examining the possible effects of inhibition, perceptual speed, working memory and scene context on perceptual change detection performance. In an effort to broaden the range of individual differences, both young and old adults participated in the studies. Results indicated that perceptual change detection was best characterized by a convergence of attentional breadth and visuo-spatial working memory measures. To a lesser extent, perceptual speed was also associated with change detection performance, but the ability to inhibit irrelevant information (i.e., inhibition) had no detectable, independent relationship. Findings also revealed that change meaningfulness (i.e., relevance to the context of the scene) had a smaller impact on performance than did salience, especially for the older adults. An examination of eye movement behaviors indicated that early in their viewing of the scene, older adults landed on highly meaningful changes that were also of low salience; however, they were not able to explicitly detect the change. Further examination of eye movement behaviors suggested that fixating the change did not ensure detection, rather the duration of processing in the change area increased the likelihood of successfully detecting the change and older adults required longer processing times than younger adults.

DEDICATION

This work is dedicated with all my heart to Jordi and Zac, and to JT, who is an unquestionably supportive friend and companion.

ACKNOWLEDGMENTS

In conducting this research, I have received invaluable aid from a number of faculty, friends and colleagues. I would first like to acknowledge the U.S. Air Force and Colonel David B. Porter, for their sponsorship and for making it possible for me to participate in this research.

I would especially like to thank my advisors, Dr. Arthur F. Kramer and Dr. David E. Irwin, for their helpful criticisms, suggestions, and encouragement. I have benefited immeasurably from their guidance and I owe them an immense debt of gratitude for making this a challenging and rewarding experience.

Many practical and thoughtful suggestions were provided by Dr. Christopher D. Wickens, my "applications conscience", and Drs. Brian Ross and Tamara Rahhal provided support and valuable input as committee members.

I am indebted to Roger L. Marsh, for his programming talents and for devoting many hours to solving the technical challenges of this project. Thanks are also due to Meg Vais, Terri Graham, Liz Podczerwinski, Bonnie Grudowski, and Shawn Bolin for their assistance in many hours of data preparation and collection.

Among other kind friends who contributed to this project, Jake Seagull, Angela Colcombe, Cate Harrison, Lisa Boyce and especially Michelle Yeh gave generously of their time and were invaluable in helping me clarify the findings. I would like to thank Soo-Jin Lee for carrying on this research and I hope I have helped her set out on the right path. Finally, I gratefully acknowledge my family, JT, Jordi and Zac Harris; my parents, Homer and Lorna Pringle; and my sister and brother, Erin Pringle and Cameron Pringle, for their continued and unwavering support.

This research was supported by a grant from the National Institute on Aging (AG14966) and a cooperative research agreement from the Army Research Laboratory (DAAL01-96-0003) to Art Kramer.

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INTRODUCTION

Whether one is a pilot landing an aircraft, a driver navigating rush hour traffic or a doctor in the midst of surgery, accurately perceiving details and changes in the environment is fundamental to the operator's ability to successfully comprehend the current situation, project the future state of the system and plan appropriate actions (Endsley, 1995; see also Endsley, 1988). For example in driving, operators should be aware of the details concerning cars, lights, street signs or pedestrians so that if a car suddenly stops in front of them, a light changes from yellow to red, or both, they may respond in a timely and appropriate manner (e.g., slamming on the brakes). Unfortunately, research has demonstrated that when change coincides with an interruption to the ongoing visual processing, observers are surprisingly slow to detect the difference (if it is detected at all), suggesting that observers typically lack such a detailed representation.

In fact, perceptual change detection is limited (i.e., slow or even nonexistent) under a variety of circumstances, such as during saccadic eye movements (Grimes, 1996; McConkie & Currie, 1996; Henderson, 1997; Irwin, 1991), simulated saccadic suppression (i.e., "flicker"; Rensink, O'Regan & Clark, 1997), blinks (O'Regan, Deubel, Clark & Rensink, 2000), mud splashes (O'Regan, Rensink & Clark, 1999), dynamic simulated scenes (Wallis & Bulthoff, 1998), movie clips (Levin & Simons, 1997) and even real world interactions (Simons & Levin, 1998). What is more, perceptual change detection is less than perfect for a variety of changes. For example, transformations of object features (e.g., color) and objects themselves (e.g., substituting or deleting objects) are not readily detected when accompanied by an interruption in visual processing (Mondy & Coltheart, 2000). While detecting changes concurrent with interruption is indeed difficult, it is not impossible. Accordingly, some limited representation of the scene must be maintained in order for successful detection to occur (a few objects and features in transsaccadic memory; Currie, McConkie, Carlson-Radvansky & Irwin, in press; Irwin & Gordon, 1998).

The purpose of the research described here is to investigate the influences that impact the ability to detect scene changes under simulated saccadic suppression conditions. Specifically, the influences that are examined included scene context and individual differences in attention, working memory, perceptual speed and the ability to inhibit irrelevant information. The relations among these factors are depicted in Figure 1, which is used as a framework for the following review of the literature.

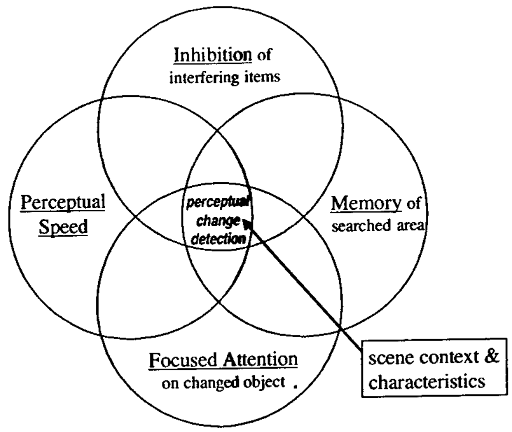

Figure 1. Potential factors influencing perceptual change detection performance.

As shown in Figure 1, multiple factors are proposed as important determinants of perceptual change detection performance. The figure is not intended to exhaustively represent factors involved in perceptual change detection, but rather to depict the most substantial ones. At least four factors are measurable abilities within individuals: inhibition of irrelevant information, perceptual speed, memory (of the searched area) and focused attention (on the object being changed). The variance of these factors across individuals reflects the relative efficiency of perceptual change detection. Additionally, perceptual change detection performance across individuals should be affected by extrinsic factors such as the context in which the scene occurs and characteristics of the change (e.g., salience).

To some extent the individual factors are interrelated, as suggested by the figure (and, for example, by findings that slowing on simple perceptual tasks can account for a large amount of variance in declines in working memory capacity; e.g., Fisk & Warr, 1996). At the same time, they may independently contribute to differences in complex cognitive processes such as perceptual change detection (for a discussion of the independent contributions of working memory and perceptual speed to other complex cognitive processes, see Verhaeghen & Salthouse, 1997; Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, & Gaines, 1996).

Previous research in perceptual change detection has typically acknowledged the influence of focused attention (e.g., Rensink et al., 1997; Levin & Simons, 1997), but the contributions of the other factors have been relatively unexplored in this paradigm. As will be discussed, both the shared and independent influences of the factors in Figure 1 were evaluated in this study. Experiment 1 examined the independent role of focused attention in perceptual change detection by measuring individuals' breadth of attention in a functional field of view task (FFOV)[1] and then related it to the speed with which they

[1] It should be noted that focused visual attention will occasionally be referred to as attention in this document. Furthermore, the measure of focused visual attention used throughout the document is breadth of attention, measured by performance on the FFOV task.

detected changes in scenes. It was hypothesized that subjects with broader attentional windows would be able to detect changes with fewer perceptual samples, based on findings that changes in scenes are detected by sequentially sampling portions of the scenes with an attentional window. Change characteristics (i.e., salience, task meaningfulness and eccentricity) were also examined for their effect on perceptual change performance, based on findings for their ability to influence attention (e.g., Rensink et al., 1997; Ball, Beard, Roenker, Miller & Griggs, 1988) and visual search (e.g., Nothdurft, 1993).

Although it has been implied that focused visual attention is the sole determinant of perceptual change detection performance, additional factors may contribute to this relationship. Experiment 2 evaluated other factors for their potential independent contributions to perceptual change detection, as well as their shared ability (along with attention) to account for perceptual change detection performance. One factor was working memory capacity, given the hypothesis that perceptual change detection relies on maintaining a representation of locations and objects already viewed in a scene. In addition, perceptual speed was considered relevant due to the nature of the perceptual change detection task (i.e., it requires observers to rapidly search and quickly respond upon detecting the change). The ability to inhibit irrelevant information was examined, since knowledge of a specific change in one trial should be irrelevant for the detection of change in a subsequent trials. Because Experiment 1 did not address the possibility that change can be represented without explicit awareness (as some research suggests; see Fernandez-Duque & Thornton, 2000; Rensink, 1998), Experiment 2 examined this issue by employing an implicit measure (i.e., eye movements). Finally, based on findings in Experiment 1 that change relevance (or meaningfulness to the task) did not have a strong influence on perceptual change detection (especially for some subjects), an enhanced scene context was examined for its ability to guide attention to task-relevant changes.

Returning to the principal factors in Figure 1, large differences between individuals are often revealed on measures of focused attention, working memory and perceptual speed, generally showing a disadvantage for late adulthood. For example, compared with younger adults, older adults have a narrower breadth of attention, smaller working memory spans, slower perceptual processing and a decreased ability to inhibit irrelevant information (Ball et al., 1988; Sullivan, Marsh, Mathalon, Lim & Pfefferbaum, 1995; Salthouse, 1992; Hasher & Zacks, 1988). Hence, to further explore the relationships between these factors and perceptual change detection, both young and old adults were included in these studies. Additionally, it was hypothesized that perceptual change performance would decline with age, given the findings for the age-related decrements in breadth of attention, working memory span, perceptual processing, and inhibition.

Thus, the role of attention in perceptual change detection is discussed first, followed by an explanation of how this issue was addressed in Experiment 1. Then some of issues raised in Experiment 1 are examined in Experiment 2, ending with a discussion of these findings and the general implications of both studies.

The Role of Focused Attention in Perceptual Change Detection

A frequently cited ingredient for successful perceptual change detection is focused attention, especially when the task involves explicitly identifying changed objects. The link between attention and change detection has only been suggested by the perceptual change detection research, but not yet convincingly established. This section covers the background of the hypothesized link between attention and change detection, followed by a discussion of a particular measure of attention, the functional field of view, that may shed light on the issue by relating differences in attentional breadth to perceptual change detection.

One approach to investigate the attentional hypothesis is saccade-contingent change detection. In a saccade-contingent change paradigm, observers detect changes in stimuli that occur during the course of an eye movement to a new location. McConkie and Currie (1996) investigated observers' ability to detect shifts in stimulus size or location while viewing naturalistic scenes. Change detection rates in this study were very poor overall, ranging from 0-15%, and they depended on the magnitude of the objects' displacement (i.e., bigger shifts led to better detection). Importantly, change detection was greatly influenced by the direction of the eye movement, such that detection was greatest for shifts in the direction of the saccade. This result led McConkie and Currie to support a saccade target theory of visual stability in which the landing position of the saccade is critical for the perception of a stable environment and hence, the detection of change. One apparent weakness in drawing this conclusion is that the saccade target always moved with its background, so it is difficult to determine if the objects surrounding the saccade target also influenced perceptual change detection.

To address this shortcoming, Currie and colleagues (in press) compared the effects of four types of saccade-contingent changes to scenes. These changes included: a shift in the target object, a shift in just the background, a shift in both the target object and the background, or no shift (Currie et al., in press). Currie et al. (in press) found support for a weak conceptualization of the saccade target theory. That is, a shift in the saccade target alone was detected more often than a shift in position for all objects in the scene, which, in turn, was detected more often than a shift in just the background. This suggests that the landing position of the eyes is primarily important for detection of change, but the area surrounding the saccade target also plays a smaller role.

One explanation for the saccade target advantage is that attention precedes the eyes to the saccade target (Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher & Blaser, 1995; Deubel & Schneider, 1996) and thereby increases the chances that information on the target object and nearby features is retained (Irwin, 1992). This possibility was supported by a saccade-contingent study that separated where subjects attended through instruction and where they moved their eyes as indicated by a tone cue (Irwin & Gordon, 1998). In this study, no objects were changed, but subjects were required to report the identity and location

of the letter (which disappeared during the saccade) that previously occupied the probed space. In general, results indicated that subjects were as accurate in reporting information when their eyes moved toward an unattended target location as they were in reporting information at an attended location when the eyes moved away from the target location, thus lending support for the saccade-target theory.

Unfortunately, saccade-target theory does not address performance as the eyes move away from the target. Irwin and Gordon (1998), for example, found accuracy remained above chance when the eyes moved away from the probed location (although, as mentioned earlier, it was much better when the eyes moved toward the probed location). Another study, Henderson and Hollingworth (1999b), evaluated observers' ability to detect change contingent on the eye moving away from a specified target, in addition to studying change contingent on the eye moving to a specified target. Consistent with saccade target theory, results showed that change was detected much more frequently when the eyes moved directly to the object undergoing change. Yet, when the eyes moved away from the target object, change was also detected at a high rate (relative to movements from other object locations), suggesting that the landing position of the eyes is not sufficient for change detection. Finally, change was detected further in the periphery as the eyes moved toward a deleted object (i.e., that was present just prior to the saccade), than compared to when the eyes moving toward a rotated object, indicating that the characteristics of change affect their detectability.

Overall, studies employing a saccade-contingent change paradigm demonstrate that change detection is difficult when it occurs during the movement of the eyes and provide support for the hypothesis that attention plays a role in perceptual change detection by preceding the eye to the saccade target. The question then arises whether the failure to detect change occurs only when the eyes move, or could another mechanism produce the same result? Furthermore, would this alternative also provide evidence for an attentional role in perceptual change detection?

One alternative approach to investigating perceptual change detection is simulated saccadic-suppression change detection (i.e., flicker paradigm; Rensink et al., 1997), in which a blank screen briefly flashes between alternating presentations of a scene and a modified copy. The duration of the blank field serves as a global transient, masking the individual transients or change (Simons & Levin, 1997). This approach is distinguished from the saccade-contingent approach in Table 1.

	SACCADE-CONTINGENT APPROACH	SIMULATED SACCADIC SUPPRESSION APPROACH
Interruption coupled with change	Saccade	Global Mask
Opportunities to detect change	1	Multiple
Observer awareness of change likelihood	Low	High
Change dependency on scene viewing	High (dependent on eye movements)	Low (independent of viewing)

Table 1. Comparison of saccade-contingent and simulated saccadic-suppression change approaches.

As indicated in the table, the saccade-contingent and simulated saccadic-suppression approaches vary in several respects. One of the primary differences between the two approaches rests in the type of interruption associated with the occurrence of change. As discussed earlier, in the saccade-contingent approach, change occurs during a saccadic eye movement. The scene is always present, but saccadic suppression serves to mask the onset of change and hence, change is difficult to detect. In the simulated approach, change is not linked to the movement of the eyes. Instead it appears after a briefly flashed blank screen (or global mask) of approximately the same duration as a saccade. The change appears with the next presentation of the scene, but due to the interruption in processing, it is difficult to detect. Local masks produce similar effects (O'Regan, Rensink & Clark, 1999).

Another key difference between the two approaches lies in the number of opportunities an observer has to detect a scene change. In the saccade-contingent approach, there is only one opportunity to detect the scene change. In the simulated saccadic-suppression approach, change repeatedly appears, until either the observer detects it or a given period has elapsed. The two approaches also typically differ in terms of the observer's awareness of the likelihood that a change is present on a given trial. In the simulated approach, observers are informed that a change occurs on every trial. On the other hand, change does not occur on each trial in the saccade-contingent approach, and thus, some degree of uncertainty is inherent on any given trial. As will be reported in more detail below, perceptual change detection is nonetheless difficult in the simulated saccadic-suppression approach, despite providing observers with the knowledge that a change is always presented.

The last quality distinguishing the two approaches in Table 1 is whether the appearance of a change is dependent on scene viewing. For the saccade-contingent approach, a change is highly dependent on scene viewing and requires precise eye monitoring equipment. In other words, the appearance of a change is contingent on where or how often the eyes move while scanning the scene (for an example of change dependence on eye location, see Henderson & Hollingworth, 1999b; for dependence on the number of eye

movements, see McConkie & Currie, 1996). Alternatively, a change is not related to how the scene is scanned (i.e., low dependence) with the simulated saccadic-suppression approach and thus, eye position is not typically recorded. In sum, these two approaches to perceptual change detection have unique methodological features that will be informative in evaluating the attentional hypothesis. Evidence from a simulated saccadic-suppression approach will now be considered.

Studies employing a simulated saccadic-suppression paradigm (i.e., a flicker paradigm) suggest that any interruption to visual processing can cause "change blindness" (Simons & Levin, 1997) and that the attentional role in perceptual change detection is not necessarily tied to eye movements (Rensink et al., 1997; Levin & Simons, 1997). Rensink, O'Regan and Clark (1997) employed a flicker paradigm in order to investigate observer latencies in detecting changes to 48 photographs of everyday scenes. In their experiment, a brief gray field was presented for 80 ms between two successive views of a scene, one modified and one original (240ms each). The images alternated until the observer responded or until 60 seconds elapsed. The modification consisted of a change to a single object in the scene and was scored independently as having central or marginal interest, relative to other events depicted in the scene. The results showed that observers had difficulty detecting change (averaging 7.8 seconds to detect change), suggesting that the flickering blank fields masked the transients occurring with the change onset. Rensink et al. found that changes to items of central interest were detected faster than changes to items of marginal interest, even though marginal interest changes tended to be larger on average (22° of visual angle compared with 18° of visual angle for central interest changes).

Rensink et al. (1997) proposed that when flicker delocalizes the motion signals that normally accompany changes in scenes, only low-level static properties of the scene objects (i.e., stimulus attributes) and the higher-level cognitive processes (i.e., volition) are left to guide attention. At that point, perceptual change detection will require "a slow, item-by-item scan of the entire image, giving rise to long identification times" (Rensink et al., 1997, p. 372). Thus, attention and perceptual change detection performance might be linked because objects of central interest in a scene guide attention via higher-level (i.e., goal-directed) cognitive processes.

In contrast with the endogenous control of attention employed by Rensink et al. (1997), Scholl (2000) examined exogenous attentional capture in a flicker paradigm. Attentional capture was induced by late-onsets and color-singletons at locations where change would eventually occur (compared with locations where change did not occur). Change blindness (i.e., time to detect change) was attenuated at locations capturing attention exogenously by approximately 2 seconds. It is possible that the influence of exogenous capture of attention was brief in comparison with endogenous control of attention. Indeed, the exogenous capture of attention did not ensure immediate change detection when the onset or singleton coincided with the change (detection latencies exceeded 3.5 seconds). Yet, endogenous control of attention did not appear

to change over the course of the experiment, as evidenced by comparison of the early and late trials in the experiment where change coincided with the onset.

Finally, Hollingworth and Henderson (1998) investigated the attention hypothesis by monitoring eye movements during a flicker paradigm. In their study, observers had up to 20 seconds to detect a change in a virtual scene (changes consisted of deleting or rotating objects). Changes were generally detected within 5 seconds, and accuracy was above 97%. Analyses of fixation positions at the time of detection indicated that as a group, observers generally detected change when they fixated the object. A closer examination of fixation patterns, however, revealed differences between observers. For example, several observers detected a large proportion of deletion changes while fixating regions greater than 2.5° away from the object being changed. On the other hand, one observer was always within 1° of the change at the time of detection (for both deletion and rotation changes). Hollingworth and Henderson (1998) conclude that fixation position on the changed object generally drives change detection (requiring overt attention), although particularly salient changes may be detected in the periphery. It is not clear from these results, unfortunately, why some observers would detect the same change in the periphery, while others would not.

In summary, these studies seem to indicate that focused attention (guided by items of central interest, or alternatively, measured by the eye's fixation point) is uniquely responsible for perceptual change detection (although additional factors may play a role, this will be addressed in Experiment 2). If attention is responsible for perceptual change detection, then it would be reasonable to assume that individual differences in attentional skills and abilities would correspond to differences in perceptual change detection performance. A converging operation that would aid in further examining the relationship between perceptual change detection and attention would be to explore individual differences in attentional breadth to individuals' ability to detect changes in realistic scenes. More specifically, measures of the functional field of view (FFOV) derived for each subject can be related to the speed with which subjects can detect a variety of different types of changes in scenes. The FFOV as a measure of attentional breadth is examined in the next section.

Individual Differences in Attention and the Functional Field of View

The useful or Functional Field of View (FFOV) represents the spatial area that is needed to successfully perform a specific visual task without invoking eye or head movements (Mackworth, 1965, 1976; Ball, Roenker & Bruni, 1990). Typically, the FFOV is defined as the distance from fixation at which a given task is reliably performed. FFOV tasks generally consist of detecting, identifying or localizing targets in the periphery and increasing task demands generally result in a decrease in the size of the FFOV. In addition to measuring visual periphery sensitivity, the FFOV incorporates tests of selective attention, divided attention, and perceptual speed, which cannot be assessed with standard perimetric measures. In

fact, Ball and Owsley (1991) report 50% of participants in their study had visual health within a normal range but showed impairments on FFOV tasks.

Some of the earliest work on the functional field of view, performed by Mackworth (1965), suggested that the purpose of a contracting attentional window is "to prevent overloading of the visual system" (p. 67). Not much has been changed since Mackworth (1965) in terms of our understanding of the purpose of this variable sized attentional window, although we have expanded our knowledge on the mechanisms affecting its size. According to Ball et al. (1990), three factors are important in characterizing individuals with a narrower FFOV (here described as UFOV):

> *(1) reduced speed of visual processing (as reflected by a greater impact of reducing stimulus duration on UFOV area), (2) reduced ability to divide attention (as reflected by a greater impact of increasing center task complexity on UFOV area), and (3) reduced salience of the target against its background (as reflected by a greater impact of distractors on UFOV area). (p. 499)*

These factors are thought to have independent influences on FFOV since individuals may show declines in one or several of the factors (Ball et al., 1990). Furthermore, this highlights a delicate relationship between FFOV and perceptual abilities. On the one hand, the FFOV relies upon the quality of the perceptual information received via the visual system. On the other hand, perceptual decline is not a necessary condition for a reduced FFOV. In fact, many adults with impairments in the FFOV had normal visual fields, although some individuals who had serious visual field loss also showed an impairment in the FFOV (Ball et al., 1990; Ball, 1997). Finally, the size of FFOV may improve with practice, reducing the likelihood that FFOV is purely a sensory phenomenon, since sensory deficits are not recoverable with practice once lost (Gould & Carn, 1973; Ball et al., 1988).

Determining the size of an individual's breadth of attention can be useful in predicting performance on complex tasks. Bellamy and Courtney (1981), for example, measured the extent to which "working field of view" could be useful for selecting individuals for industrial inspection tasks and observed a correlation of 0.92 between their FFOV and success in multiple fault search tasks. O'Neill, Batten and Woontner (as cited in Star Mountain, Inc., 1995) found broader FFOVs corresponded to a higher likelihood of detecting a partially concealed vehicle and faster detection times for similar tasks. It would seem that the FFOV's ability to assess selective attention would be especially relevant for a visual search task such as perceptual change detection.

The functional field of view is also a useful tool for revealing individual differences in attentional breadth, since the size of the FFOV varies both within and across individuals. Within individuals, conditions that affect the size of the FFOV include information density (i.e., number of distractors), discriminability of the target from its background, display processing time and foveal load (Mackworth,

1965, 1976; Williams, 1985, 1989; Ball et al., 1988, 1990; Scialfa, Kline & Lyman, 1987). For example, Williams (1985) found that foveal load, defined as the cognitive load of processing a foveal stimulus, interacted with retinal eccentricity on a peripheral identification task. Low foveal load had less of an impact on the identification of the orientation of a peripheral line (located 3, 6, or 9° from center) than did a high foveal load. Even outside the laboratory, the FFOV seems to be affected by foveal load. Miura (1990) examined changes in the functional field of view as a function of driving load. Two participants verbally responded to a random light appearing at various spatial and temporal intervals while driving in light or heavy traffic conditions (taken over 60 different driving periods). With increasing demands in traffic, the eccentricity at which drivers could detect the stimulus narrowed considerably (Miura, 1990).

A number of studies suggest that when comparing across individuals, age accounts for large differences in FFOV. That is, the elderly show constricted FFOVs relative to younger observers (Sekuler & Ball, 1986; Ball et al., 1988; Ball, Owsley, Sloane, Roenker & Bruni, 1993; Scialfa, Thomas & Joffe, 1994). For example, older observers required to localize a peripheral target (appearing at 5°, 10°, or 15° from center) and in the presence of 47 distractors, show a significant decrement in performance relative to their young counterparts (Sekuler & Ball, 1986). Later evidence indicated that age-related differences also existed for localization accuracy of isolated peripheral targets (occurring at 30° eccentricity), and these differences were further magnified when the targets were presented with distractors (Ball et al., 1988; but see Seiple, Szlyk, Yang & Holopigian, 1996, for evidence that older adults have a degradation across the entire field of view, not a *constricted* FFOV).

The FFOV account for age-related differences in detecting peripheral targets has some limitations and does not account for results in all situations. Older adults are not disadvantaged compared with younger adults on feature searches, regardless of target eccentricity (see Plude & Doussard-Roosevelt, 1989; Foster, Behrman & Stuss, 1995; Humphrey & Kramer, 1997). Yet, a couple of issues should be considered before discounting the FFOV account for age-related differences entirely. The first is a methodological issue not adequately addressed. Given that the FFOV is based on the area within which information can be obtained without moving the eyes, then either eye movements need to be monitored or display times need to be limited in order to prevent them. Most important to consider, however, is that the size of the FFOV increases with decreasing target-distractor similarity. Thus, FFOV is magnified in feature search (with negligible target-distractor similarity) placing the most peripheral targets within the FFOV of both older and younger observers (Scialfa et al., 1994). Scialfa et al. (1994) concludes that search within an individual's FFOV (regardless of age) is largely parallel, but outside of which a serial search is conducted.

By far the most successful application of the functional field of view has been for the prediction of vehicular accident frequency in older adults (Rizzo, Reinach, McGehee & Dawson, 1997; Isler, Parsonson & Hansson, 1997). Ball et al. (1993) observed a high correlation between a reduction in the FFOV with state-

reported driving accident record for elderly adults. Measures of ocular health, cognitive function and chronological age were also considered, but were not as effective as FFOV in distinguishing adults who had been involved in crashes from those who had not. Later research strengthened this claim by showing that older individuals with a 40% or greater impairment in the functional field of view were 2 times more likely to be involved in a crash during the 3-yr follow-up period (Owsley, Ball, McGwin, et al., 1998).

In summary, the functional field of view seems to be a sensitive indicator of attentional breadth and predictive of complex task performance. Consequently, it could be useful in evaluating the hypothesis that focused attention is required to detect changes in scenes (recall that focused visual attention will occasionally be referred to as simply "attention" and that breadth of attention, measured by performance on the FFOV task, will be the measure of focused visual attention used throughout the document), and in providing insight as to individual differences in detecting change in the periphery (as in Hollingworth & Henderson, 1998). Finally, it is interesting to note that degraded driving performance can be predicted by a reduction in an older driver's FFOV, a skill that would also seem to rely on an ability to detect change in the environment.

The Influence of Change Characteristics on Attention

Studies investigating change blindness have indicated that focused attention may be required to report change in scenes and that changes to low-level visual properties of a scene (e.g., stimuli characteristics such as color and form), as well as changes to higher level cognitive properties (e.g., relevance to observer goals or interests), may guide attention to the change (e.g., Rensink et al., 1997; McConkie & Currie, 1996; Levin & Simons, 1997). Although both low- and high-level visual properties appear to be important, the two characteristics have not been satisfactorily addressed. Each of these object change characteristics will be examined in this section.

Low-level visual properties that may influence change detection include, but are not limited to the following: changes to the object's shape, size, identity, location, orientation, color or presence. A straightforward finding is that the greater the change, whether in size or location, the greater the chances are for detection (McConkie & Currie, 1996). Furthermore, changes in an object's presence (i.e., addition or deletion changes) may be detected more readily than other types of changes to the same object (e.g., orientation or color; Wallis & Bulthoff, 1998; Hollingworth & Henderson, 1998; Blackmore, Brelstaff, Nelson, & Troscianko, 1995). Finally, change seems to be detected more readily when an object switches to a completely new object (real or unreal), compared with a contour or location change in the same object (Henderson, 1997). This is consistent with an object-file theory of trans-saccadic memory (Irwin, 1996). If integrated object files are more likely to survive a saccade intact than location information, then a change in the object identity would be more likely to be detected than a change in location.

Results obtained in visual search tasks also demonstrate that differences in salience (due to color, motion, luminance or orientation) speeded detection of a target which, if non-salient, could only be detected by slower, serial processing (Nothdurft, 1993). This might also hold true in change detection, such that salient changes to objects (along the above-mentioned dimensions) are quickly detected, but this has yet to be directly addressed in the perceptual change detection literature.

A great deal of the visual search literature has focused on high-level visual properties, often using "semantic informativeness" as the measure of interest (e.g., Buswell, 1935; Yarbus, 1967; Mackworth & Morandi, 1967; Antes, 1974). Early studies suggested that the eyes started at informative areas and then gradually moved to less informative areas over the course of viewing scenes (Antes, 1974). One drawback to these early studies is that ratings of informativeness may have been influenced by visual and/or semantic factors (Henderson, Weeks & Hollingworth, 1999; Henderson & Hollingworth, 1999a). One way to address this issue is to have raters assess *both* the semantic (high-level properties) and the visual informativeness (low-level properties) of the objects, or alternatively, experimentally compare the same objects in semantically consistent and inconsistent scenes. Using the latter approach, the evidence indicates that informative areas were *not* fixated earlier than uninformative areas (i.e., initial fixation placement), although initial fixation durations and refixation probabilities are affected by semantics (Henderson et al., 1999). Henderson et al. (1999) suggest that the initial fixation on a scene is determined by visual rather than semantic factors, although fixation duration and the number of fixations within an area are determined by the semantics of the task.

In the perceptual change detection research, high-level visual properties have not received as much attention, but they have been shown to affect overall perceptual change detection as well as detection for particular types of change. For example, changes to items of "central interest" in a scene are detected faster than changes to items of marginal interest, even when the marginal interest changes are generally larger (i.e., averaging 22° compared with 18° for central interest changes; Rensink et al., 1997). Furthermore, both task-relevance and task involvement influence the detection of change (e.g., Hayhoe, Bensinger & Ballard, 1997; Wallis & Bulthoff, 1998). In fact, Wallis and Bulthoff (1998) found that task involvement (i.e., driving) produced overall change detection costs compared with static viewing of the scenes, while detection of object changes on or near the road were enhanced. It would be interesting to know if objects near the road were detected due to their relevance to the driving task, or due to the added difficulty of the driving task limiting the driver's scan.

Overall, the results in this section support the idea that attention may be guided to change based on high-level interest (e.g., task relevance) or low-level visual properties (e.g., salience) but these characteristics have been evaluated independently and it is not clear how the relative importance of these two classes of properties is determined during scene perception and perceptual change detection.

Summary

The findings in the literature lead to several conclusions. First, perceptual change detection is difficult under a variety of circumstances that interrupt visual processing (e.g., during eye movements). Second, it appears that attention may be required to detect changes in scenes, although it has not yet been studied systematically, particularly from an individual differences perspective. Third, differences in attention both within and between individuals are reasonably measured by functional field of view tasks. Finally, low-level or high-level attributes of the changed object may influence perceptual change detection, but they are not well understood. Other important issues have been raised in the literature and will be considered, following the discussion of how Experiment 1 addressed the issues raised thus far (next section).

EXPERIMENT 1: THE ROLES OF ATTENTIONAL BREADTH AND CHANGE CHARACTERISTICS IN CHANGE DETECTION PERFORMANCE

The purpose of Experiment 1 was to investigate the relationship between individual differences in attention and change detection performance. Subjects' breadth of attention was assessed in a functional field of view task (FFOV) and then related to the speed with which individuals detected changes in scenes. Salience, meaningfulness and eccentricity of the scene changes were also examined for their effect on perceptual change performance. In an effort to broaden the range of individual differences in attentional breadth, both young and old adults participated in the study. The results are discussed in terms of the role of attention in perceptual change detection and lead to issues that will be addressed in Experiment 2.

Hypotheses

Three hypotheses were examined in Experiment 1. First, it was hypothesized that a negative correlation would be observed between change detection latency and a measure of attentional breadth (FFOV). This hypothesis is based on the assumption that changes in scenes are detected by sequentially sampling portions of the scenes with an attentional window (as in Rensink et al., 1997) and therefore subjects with broader attentional windows should be able to detect changes with fewer samples. Second, given previous findings of reduced FFOVs with increasing age, it was hypothesized that perceptual change performance would decline with age. Finally, it was hypothesized that factors shown to influence attentional control (i.e., salience, meaning and eccentricity of changes) would also influence perceptual change detection in complex scenes.

Method

<u>Participants</u>

A total of 51 people participated in the study. The 25 younger participants (13 women, 12 men) were recruited from the University of Illinois and ranged in age from 18 to 33 years (M=23 years). The 26 older participants (18 women, 8 men) were recruited from the local community and ranged in age from 55 to 80 years (M=68 years). Each subject had corrected visual acuity better than 20/40, possessed a valid driver's license for the previous 2 years, and drove over 25 miles per month. The mean number of years of education for younger adults (16.1 years, $SD=3.1$, $N=17$) was not statistically different from the mean education for older adults (14.5 years, $SD=2.4$, $N=24$; $t(39)=1.49$; $p<.07$). Education information was not available for all participants. Participants were compensated at a rate of $6 per hour for the experiment.

<u>Apparatus</u>

A Micron Millenia MME computer with a 12X16 inch Viewsonic monitor was employed. Participants rested their chins on a chin rest 56cm from the screen. A Fresnel lens was used to eliminate the

accommodation cues and to effectively present the stimuli at a distance approaching optical infinity. The Fresnel lens also increased the subjective size of the image region.

Experimental Tasks

Perceptual Change Task

The perceptual change task was conducted in the same fashion as Rensink et al. (1997). Each trial consisted of an original image (A) and a modified version (A'), which were displayed in the sequence A, A, A', A' (see Figure 2). Gray blank fields were placed between successive images to simulate a saccade and to eliminate apparent motion across image displays. Each image was displayed for 240 ms and each blank screen (gray field) for 80 ms.

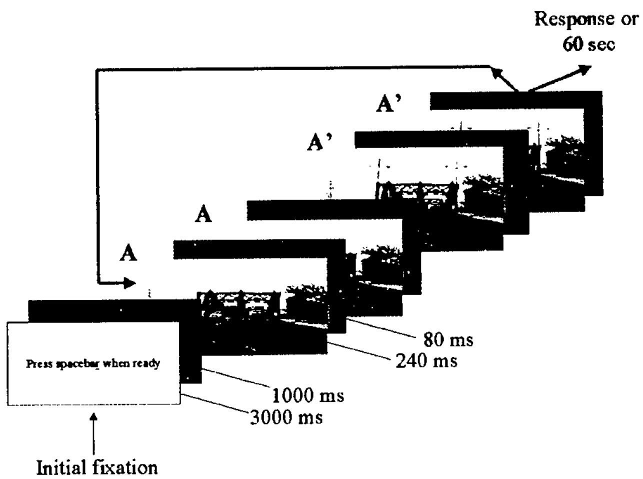

Figure 2. Perceptual change detection task (adapted from Rensink et al., 1997).

Eighty digital photographs of scenes taken from a driver's perspective inside a car were manipulated in the experiment (80 experimental trials). Images were presented to the observers as approximately 25 degrees wide and 20 degrees high. The modified version of each scene involved a change in a single object's color, location or presence. Image changes were categorized along three dimensions: eccentricity, meaningfulness, and salience. Eccentricity was measured according to the changed object's distance (in degrees of visual angle) from the center of the image, which was marked to determine an initial fixation point. Central changes fell within 6 degrees visual angle from the center of the image, while peripheral changes fell outside a radius of 6 degrees from center. Meaningfulness and salience of the change were determined separately in a pilot study (discussed below).

Participants were instructed that they would be viewing scenes taken from the driver's perspective. They were told to fixate the center of the screen and indicate to the experimenter when they were ready. Once the experimenter began a trial, subjects were allowed to search freely for the image change. When they detected the change, subjects were instructed to press the mouse button, and then to verbally describe the change. Although they were allowed to view the alternating scenes up to one minute, subjects were instructed to respond as quickly and as accurately as possible.

Participants were told of the types of changes possible (i.e., object's color, location or presence) prior to beginning the experiment and were given two practice trials to familiarize them with the task. Images and image changes (i.e., meaningfulness, salience and eccentricity) were presented in a random order for each subject. The dependent variables were the response time (RT) needed to detect the change and the accuracy of the detection.

Four factors were evaluated in the perceptual change task (i.e., age, meaningfulness, salience and eccentricity). Age served as a between subjects factor and the remaining three factors were within subjects and were randomized within trial blocks.

Meaningfulness and Salience Change Characteristics

The meaningfulness and salience characteristics of both the object and its change are likely to have a high degree of overlap, as in the case of a disappearing semi-truck (i.e., a salient, meaningful vehicle undergoing a very salient, meaningful change), but the correspondence is not perfect. For example, changing the color of a salient, meaningful object (e.g., the semi-truck) to a slightly lighter shade of gray would be a hardly noticeable, non-meaningful change. Therefore, the meaningfulness and salience characteristics of both the object and its change were determined in two separate pilot studies. The first study examined the characteristics of the *change* (i.e., a modification of the properties of an object varying over time and occasionally over spatial location), while the second study examined characteristics of the *object* undergoing change (i.e., a recognizable item with consistent spatio-temporal properties).

The first pilot study consisted of 14 younger (M=22 years) and 10 older adults (M=72 years). Participants saw two images of a scene (original and modified) on color printed pages in a notebook. Once they had correctly identified the change between the two images, they were asked to rate the change according to a 6-point Likert scale. They rated the 82 changes (including the 2 practice pictures) on one dimension (i.e., meaningfulness or salience) before rating them on the other dimension. Order was counterbalanced across participants.

Meaningfulness was defined to the raters as the relevance or importance of the change to driving performance. For example, changing the color of a restaurant sign should be given a low meaningfulness rating, while changing the color of a stoplight should be rated high. Salience was defined to the raters in

terms of low-level perceptual factors. For example, a large, bright, noticeable change should be rated as highly salient, while a small, dim, difficult to see change should be rated low.

The second pilot study was conducted in the same fashion as the first with the following exception: participants (6 young adults, M=22 years; 6 older adults, M=76 years) were asked to rate a single object in each of the 82 scenes according to the degree of the object's perceived meaningfulness and salience. The participants were not aware of object modifications, since they only viewed a single image of each scene.

Meaningfulness was again defined in terms of the object's relevance or importance to driving behavior (e.g., a stopsign has high object meaningfulness, a building has low object meaningfulness). Salience referred to the object's prominence or visibility (e.g., a large building has high object salience, a license plate has low object salience).

Analyses of subjective ratings to the 80 driving scenes (excluding the two scenes used in practice trials) were conducted to examine the range of variability in ratings of the pictures on the meaningfulness and salience scales and to determine the degree of similarity of meaningfulness and salience ratings for older and younger adults. Given the high correlation between meaningfulness and salience ratings for the objects and changes (r=.50, .77, respectively), results will be reported in terms of the meaningfulness and salience ratings of the *change*. It should also be noted that a complete set of analyses was conducted using the object ratings, and these results are consistent with the results that follow (which are based on the ratings of the change).

The mean and standard deviation of the median ratings for salience were 2.95 and 1.29, respectively. The comparable ratings for meaningfulness were 2.59 and 1.98, respectively. Thus, raters judged the scene changes as varying to a greater extent in meaningfulness than in salience. No significant differences were found between young and old observers for mean ratings of meaningfulness ($t(21)= -.78$; $p<.44$); however, older observers rated changes as more salient than younger observers ($t(21)= -3.43$; $p<.003$). Cronbach's alpha reflected high degrees of consistency for each of the rated dimensions (.91 and .94, for the rated meaningfulness and salience of the change, respectively).

For the purpose of analysis of the perceptual change performance, the 80 driving scenes were divided into four categories (i.e., low meaning/low salience, low meaning/high salience, high meaning/low salience, high meaning/high salience) on the basis of the median ratings across raters. The equivalence of the range of differences between low and high categories was then examined for the meaningfulness and salience factors. To do this, the relative differences between low and high salience and meaningfulness ratings of the pictures were recoded in terms of standard deviation (SD) units. As an example, averaging across all pictures in the low meaningfulness/low salience category produced mean meaningfulness and salience scores of 0.4 and 1.4, respectively. The comparable mean ratings for meaningfulness and salience of pictures in the high meaningfulness/low salience category were 4.1 and 1.75, respectively. The SDs for the meaningfulness and salience ratings were 1.98 and 1.29, respectively. Thus, the difference between high

and low meaningfulness for low salience pictures (high - low meaningfulness for all low salience pictures) was (4.1 - 0.4)/1.98, or 1.86 SD units. For the remaining categories, the calculated values were 1.87, 1.63 and 1.67 SD units for high - low meaningfulness for high salience pictures, and high - low salience for low and high meaningfulness pictures, respectively. Because the difference between high and low in SD units was approximately the same (i.e., 1.63 - 1.87) across categories, this analysis suggests that the meaningful changes in the pictures and the salience changes in the pictures were equated reasonably well.

Attentional Breadth Task

A measure of each subject's attentional breadth (FFOV) was obtained using a visual search task in which they searched for a target (occasionally among distractors), with the target appearing at one of three eccentricities (10, 20, or 30 degrees from fixation) along 24 positions on the display monitor (see Figure 3).

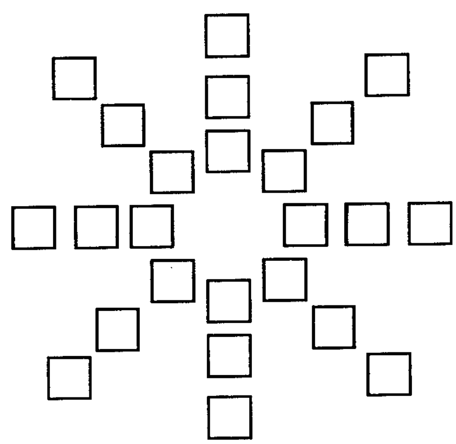

Figure 3. Possible positions for peripheral target localization task. Note that boxes did not appear on the screen during presentation of targets and distractors.

Subjects performed the FFOV task in one hour long session, completing four blocks of 144 trials each, with 24 practice trials before each block. The subject's task depended on the condition. On half of the trials, subjects were instructed to localize an oblique target that was tilted 20 degrees from the left of vertical, while on the other 50% of the trials subjects were instructed to localize a vertical target. The vertical and oblique lines presented at the peripheral locations subtended 2 degrees of visual angle and could appear along eight meridians and three retinal eccentricities (approximately 10, 20 and 30 degrees) for a total of twenty-four possible positions. Localization responses were made by moving a mouse and clicking on one of 24 marked positions on a radial pattern presented after the trial that indicated the potential locations of the target (see Figure 3). The conditions for the FFOV task are summarized in Table 2 (rows from top to bottom indicate the task type, number of distractors, target type, and degrees eccentricity of target presentation).

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Table 2. Conditions for the FFOV task (top to bottom: task type, number of distractors, target type, and degrees eccentricity of target presentation).

Target orientation was manipulated based on previous research (e.g., Treisman & Gormican, 1988; Treisman & Sato, 1990; Cavanagh, Arguin & Treisman, 1990) which has shown a search asymmetry with oriented lines. That is, oblique targets are easier to identify when accompanied by horizontal and vertical distractors than are horizontal or vertical targets among oblique distractors. Thus, varying the targets and distractors enabled an assessment of the influence of search difficulty on FFOV breadth. Targets and distractors employed in previous studies of FFOV (e.g., smiley faces and trucks; Ball et al., 1988) had no theoretical basis in the visual search literature.

Localization of these targets could occur with or without the presence of 11 distractors. On distractor present trials, oblique targets occurred within the context of vertical distractor lines, while localization of the vertical target occurred within the context of oblique distractor lines (tilted 20 degrees left of vertical). When 11 distractors were present in the display, at least one and no more than two distractors appeared on each of the eight meridians.

On half of these trials, subjects performed the localization task along with a foveal task. The foveal task consisted of deciding whether a small or large square was presented at fixation. Responses were made by moving a mouse and clicking on one of two boxes presented after each trial (see Figure 3). The small square at fixation subtended 0.5 degrees of visual angle, with the large square subtending 0.6 degrees of visual angle. The small and large squares each occurred on one half of the trials.

Before each block of trials subjects were presented with the target to be localized (i.e., vertical or oblique) and instructions concerning the foveal task. Each trial began with the presentation of a fixation cross. Once subjects had fixated the fixation cross they clicked on the mouse and the peripheral items (target, and on half of the trials, distractors) and the foveal task appeared (if applicable). The display

remained present for 250 ms. Subjects then responded to the foveal task, followed by responses to the localization task. Subjects were instructed to emphasize accuracy of responding. When the foveal task occurred with the peripheral task, subjects were instructed to perform both tasks as well as possible but to respond to the foveal task first.

The following conditions were blocked within subjects: task type (i.e., foveal or no foveal task) and target type (with the corresponding distractor type). Number of distractors and target eccentricity occurred randomly within blocks. Age was the only between-subjects variable.

Results

Three sets of analyses were performed on the data. The first set of analyses focused on the influence of age, salience, meaningfulness and change eccentricity on perceptual change detection performance. Second, analyses were conducted on the FFOV task to determine the most appropriate FFOV measure to use in the subsequent analyses with perceptual change detection performance. Finally, the relationship between performance on the attentional breadth (FFOV) task and performance on the perceptual change task was examined.

Change Detection Performance

Only correct trials were used in the RT analysis. Additionally, response times greater than three standard deviations from the mean for each age group were discarded prior to calculating mean reaction times. One younger subject did not complete the experiment and the data were not included in the analyses.

Perceptual change detection response times were logarithmically transformed in order to achieve a more normal distribution with stable variance, due to the positive skew in the original data. The logarithmic transformed perceptual change detection RTs were submitted to a four-way mixed mode ANOVA with age as a between subjects factor and meaningfulness (high and low), salience (high and low), and eccentricity (central and peripheral) as within subjects factors.

Main effects were significant for all four factors (age, eccentricity, meaningfulness and salience). Younger adults performed significantly faster than older adults (6.8 and 10.9 seconds, respectively; $F(1,48)=41.02$, $p<.001$); central changes were detected quicker than peripheral ones (7.9 and 9.4 seconds, respectively; $F(1,48)=35.14$, $p<.001$); and change detection was enhanced for meaningful changes (low = 9.0, high = 8.2 seconds; $F(1,48)=9.65$, $p<.003$), as well as for salient changes (low = 10.9, high = 6.8 seconds; $F(1,48)=313.93$, $p<.001$).

A significant two-way interaction was obtained between age and salience ($F(1,48)=6.53$, $p<.014$) and a marginally significant two-way interaction was obtained between age and meaningfulness ($F(1,48)=3.85$, $p<.056$). These interactions were mediated by the three-way interaction between age, meaningfulness and salience ($F(1,48)=7.94$; $p<.007$). This interaction is illustrated in Figure 4. Scheffé

post-hoc analyses indicated that increasing meaningfulness had no effect on performance for either age group when changes were highly salient. On the other hand, when salience of the change was low, increasing meaningfulness aided the performance of young ($p < .001$), but not old adults.

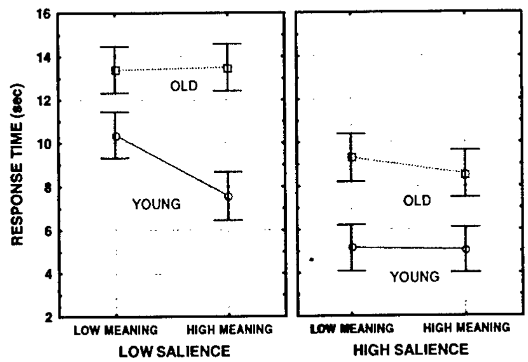

Figure 4. Mean RTs for the perceptual change task for the age X salience X meaningfulness interaction.

A significant three-way interaction was also found for eccentricity X meaningfulness X salience ($F(1,48) = 9.64$; $p<.003$). This interaction is illustrated in Figure 5. Post-hoc analyses revealed that central changes were detected faster than peripheral changes only when changes were of both high meaning and high salience ($p<.001$) and that more meaningful changes were detected faster unless they were peripheral and of high salience ($p<.07$).

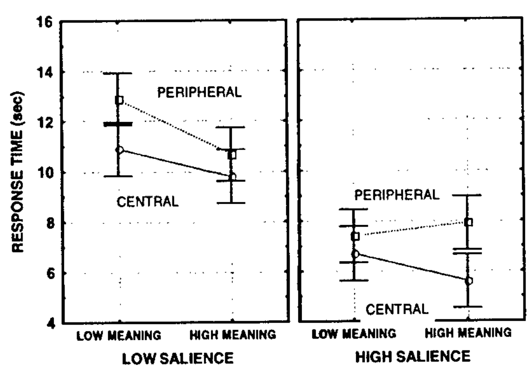

Figure 5. Mean RTs for the eccentricity X salience X meaningfulness interaction on the perceptual change detection task.

Mean accuracy for younger and older groups for each level of eccentricity, meaningfulness and salience are provided in Table 3. Inaccurately identifying the photograph change and not finding the change within the one-minute time limit were both considered errors. A four-way mixed mode ANOVA was performed on the accuracy data, with age as a between subjects factor and meaningfulness, salience, and eccentricity as within subjects factors. Main effects were significant for age ($F(1,38) = 39.8$; $p<.001$), eccentricity ($F(1,38) = 31.7$; $p<.001$) and salience ($F(1,48) = 64.0$; $p<.001$). Younger adults were more accurate overall in detecting changes than older adults. Additionally, accuracy was higher for changes

occurring centrally compared with peripheral changes, and changes with high salience compared to low salience. Significant two-way interactions were found for age X salience ($F(1,48) = 19.3$; $p<.001$) and meaningfulness X salience ($F(1,48) = 4.7$; $p<.03$). Older adults showed larger performance costs with low levels of salience than younger adults, perhaps due to a ceiling effect for younger adults' accuracy. There was a larger difference between low and high salience at low levels of meaningfulness, relative to high levels of meaningfulness.

	Younger		Older	
Condition	M	SD	M	SD
Central, Low Meaning, Low Salience	93.7	9.6	77.2	16.3
Central, Low Meaning, High Salience	99.0	5.1	94.9	10.8
Central, High Meaning, Low Salience	96.7	7.6	79.6	22.4
Central, High Meaning, High Salience	99.7	1.4	92.2	8.3
Peripheral, Low Meaning, Low Salience	90.2	8.0	71.9	19.7
Peripheral, Low Meaning, High Salience	99.3	2.4	90.0	7.8
Peripheral, High Meaning, Low Salience	91.7	10.2	71.3	19.2
Peripheral, High Meaning, High Salience	92.6	5.1	86.0	8.9

Table 3. Mean accuracy for young and old adults by level of eccentricity, meaningfulness and salience. Note that the values represent mean percentages of correctly identified changes for younger (n=24) and older (n=26) adults.

FFOV Task

Given that the size of the FFOV is influenced by a variety of factors, it was necessary to evaluate the FFOV and determine the most appropriate subtask measure to use in the subsequent analyses with perceptual change detection performance. Separate analyses were conducted for the foveal and peripheral task components of the FFOV task; however, given that the primary objective of employing the FFOV task was to quantify the costs of increasing target eccentricity (i.e., attentional breadth) across both age groups, the following analyses focus on results from the peripheral localization task. Foveal task results are of lesser importance in assessing attentional breadth and hence, are reported in Appendix A.

Within the peripheral localization task, analyses examined the effects of age, target eccentricity, foveal load (i.e., with or without a foveal task), target type (i.e., oblique or vertical) and the number of distractors (i.e., none or eleven). Univariate ANOVAs were carried out for the accuracy and response time for each trial. When the foveal task was performed (i.e., 50% of all trials), trials were accepted only when

the foveal stimulus was correctly identified; otherwise, all trials were included in the analyses. Accuracy and response times were recorded, although participants were encouraged to emphasize accuracy and were allowed an unlimited amount of time to respond.

Of the 31 possible effects for the accuracy on the peripheral localization task, 25 of them were significant ($p<.05$; refer to Appendix B), including the five-way interaction between age, foveal load, target type, eccentricity and number of distractors ($F(2,98)=4.56$; $p<.013$). Of particular interest are the age-related effects of decreasing accuracy with increasing eccentricity, which were captured by two significant three-way interactions (Age X Target X Eccentricity; Age X Eccentricity X Distractors). Before discussing these effects, a closer look at each main effect is warranted.

In general, the accuracy of localizing peripheral targets was hurt by older age, the presence of distractors, searching for vertical targets (among oblique distractors), simultaneously performing a foveal task, and increasing target eccentricity. These main effects are consistent with previous literature (e.g., Ball et al., 1988; Scialfa et al., 1994; Treisman & Sato, 1990; Cavanagh et al., 1990). It should be noted that the drop in accuracy due to eccentricity was greatest between 10 and 20 degrees; the smaller decline between 20 and 30 degrees may be attributed to a floor effect at 30 degrees.

These main effects were mitigated by several significant interactions (see Appendix B). Several lower order interactions will be discussed briefly, followed by a more detailed description of the two pertinent 3-way interactions. Older subjects had lower overall accuracy and were more negatively affected by foveal task load and the presence of distractors than their younger counterparts. Although older subjects also had lower accuracy overall for both target types, the decrease in accuracy due to vertical targets was not as severe, perhaps due to reaching a floor in performance sooner than younger adults. The remaining noteworthy two-way interactions show that eccentricity effects are mitigated by distractors, and age (#Distractors X Eccentricity, Age X Eccentricity). The interaction between the number of distractors and eccentricity demonstrates that the decrease in accuracy with increasing eccentricity applies only when distractors are present. Otherwise, performance is equally high at each level of target eccentricity.

Of primary interest was the finding of a trend for decreasing accuracy with increasing eccentricity, emphasized in older adults. Indeed, the Age X Eccentricity interaction was significant ($F(2, 98) = 31.423$; $p<.000$), however older adults only showed the decreasing accuracy trend between 10 and 20 degrees eccentricity (again, the lack of a difference between 20 and 30 degrees is most likely due to a floor effect). Accuracy linearly decreased for younger adults across all eccentricities. This finding is not meaningful when considered alone, given that the interaction was mitigated by several significant 3-way interactions. These higher order interactions will now be discussed.

The mitigating factors for the Age X Eccentricity interaction can be best understood in terms of two significant 3-way interactions between age, target type and eccentricity and age, distractor presence and eccentricity, depicted in Figures 6 and 7.

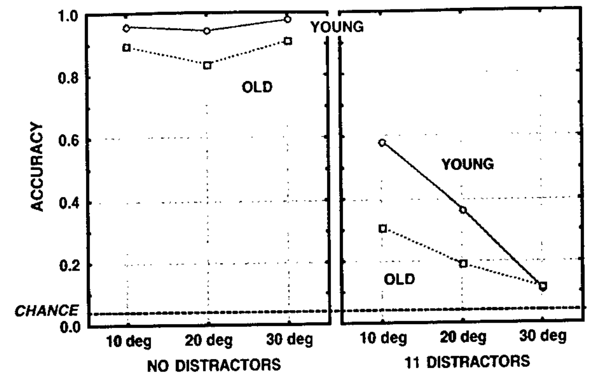

Figure 6. Mean accuracy for the FFOV task for the age X eccentricity X #distractors interaction.

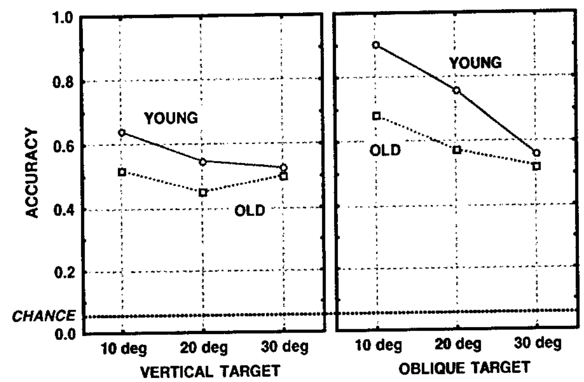

Figure 7. Mean accuracy for the FFOV task for the age X eccentricity X target type interaction.

Of interest is the lack of an eccentricity effect in many of the conditions. In fact, the best evidence for an eccentricity effect across both age groups is with distractors (Figure 6) and with oblique targets (Figure 7). Further examination of significant higher-order interactions (namely, the five-way interaction) revealed the best combination of conditions for a linear decrease in accuracy with increasing eccentricity across age groups occurred when oblique targets were presented with vertical distractors and without a foveal task. Other conditions showed eccentricity effects for only one age group (e.g., only young adults exhibited an eccentricity effect when a foveal task, and oblique targets appeared among vertical distractors; older adults in this condition performed at minimal levels for all eccentric positions) or neither age group (e.g., no distractors, no foveal task and oblique targets revealed both younger and older adults performed at ceiling levels).

The above results demonstrated that performance on the FFOV task was influenced by a number of factors and hence, the combination of conditions for estimating the size of the FFOV needed to be carefully weighed in order to reflect a linear decrease in accuracy for both age groups, across all eccentricities. A linear decrease was desired across age groups and eccentricities in order to have the best opportunity to capture individual differences in attentional breadth, which would later serve to predict

perceptual change detection performance. With that in mind, the size of the FFOV was determined on the basis of a best fitting line of each subject's accuracy in localizing the oblique target among 11 vertical distractors (see Figure 8).

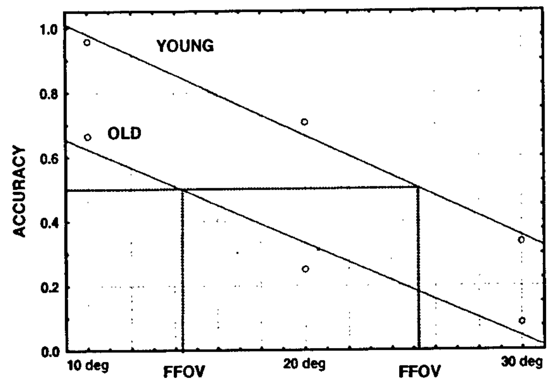

Figure 8. The size of the FFOV, derived from the eccentricity at which 50% accuracy is achieved on a best fitting line for the condition with oblique targets, vertical distractors and without a foveal task. Actual data from one younger and one older adult are shown.

Specifically, the size of an individual's FFOV was defined as the eccentricity at which 50% accuracy was achieved on a regression line of performance on the FFOV task, for the condition when a oblique target appeared among 11 vertical distractors, without a foveal task. It should be noted that this approach is analogous to that taken in other attentional breadth research (e.g., Ball et al., 1988). The mean of the slopes was -.034 (range -.02 to -.05) for younger adults and -.032 (range -.01 to -.05) for older adults. If the regression line did not intersect 50% accuracy at a positive value of eccentricity (i.e., 0 degrees of eccentricity or greater), then the size of the individual's FFOV was set to zero.

<u>Relationship Between FFOV and Change Detection Performance</u>

The third set of analyses examined the relationship between performance on the FFOV task and performance on the perceptual change task. Recall that the size of the FFOV was determined on the basis of subjects' accuracy in localizing oblique targets appearing among 11 vertical distractors at various eccentricities (i.e., the 50% accuracy point on a linear function relating localization accuracy to eccentricity; Figure 8).

The scatter plot representing the relationship between the estimated size of the FFOV and perceptual change detection latency for all subjects is depicted in Figure 9. A larger FFOV corresponded to faster detection of object changes ($r = -0.68$, $p<.001$). This trend was found for both younger and older adults when analyzed separately ($r= -0.50$, $p<.01$; $r= -0.51$, $p<.01$, for younger and older adults, respectively).

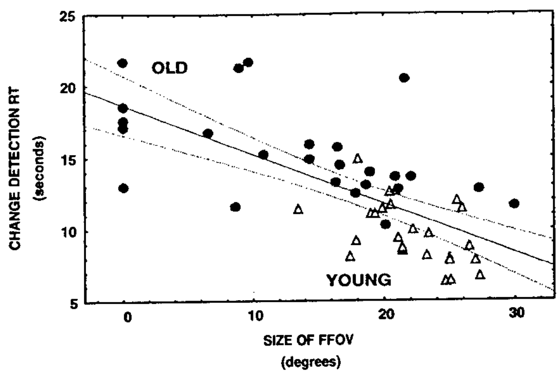

Figure 9. Correlation between perceptual change detection response time (sec) with breadth of attention (size of the functional field of view in degrees visual angle). Young adults are depicted as hollow triangles, while older adults are depicted as filled circles. The solid line represents the best fitting linear function relating change detection RT to FFOV size across all participants. The dashed lines represent the 95% confidence limits.

Discussion

The goals of Experiment 1 were to examine the effects of age and characteristics of the change on change detection performance and to determine the relationship between breadth of attention (FFOV) and perceptual change detection. Overall, the results support three conclusions: change is difficult to detect under flicker conditions, especially for older adults; detection is mediated by the characteristics of the change; and individual differences in attentional breadth are highly correlated with perceptual change detection performance.

Age, Change Characteristics and Change Detection

The results were generally consistent with the perceptual change blindness literature, with the average time to detect a change under the best of circumstances approximately 5 seconds. Furthermore, the characteristics of the change (eccentricity, salience and meaningfulness) showed interacting effects on change detection performance.

These results shed light on the role of top-down and bottom-up factors in change detection. Meaningfulness had a smaller impact on performance than did salience, especially for the older adults. This occurred despite the fact that the difference between high and low meaningfulness of changes to pictures was judged to be larger (M = 1.87 SD units) than the difference between high and low salience changes (M = 1.65 SD units) by raters. These results suggest that attention guided by meaningfulness (i.e., higher level processes) is not as powerful as attention guided by salience (i.e., lower level visual processes) in change detection, especially for older adults. One possible explanation for the relatively modest effect of meaningfulness is that the context might not have been sufficiently realistic for subjects to consider themselves "in the driver's seat". Additionally, salience, through low-level perceptual means, appears to be quite effective in drawing attention to a change. Although salience has not been directly assessed in

previous change detection experiments, the results obtained here are consistent with visual search results (Nothdurft, 1993; Theeuwes, 1996; Yantis, 1996, 1998).

Rensink et al. (1997) found some evidence for change characteristics influencing perceptual change detection. Specifically, they found that changes to items of central interest were detected faster than changes to items of marginal interest, even though marginal interest changes tended to be larger on average. Although these results may, at first glance, appear to suggest a different conclusion than that reached in the present study (i.e., that interest (meaningfulness) might be more relevant than size (salience)), there are two issues which need to be considered. First, the size of the change was not the only criterion for highly salient changes in this experiment. Salience also encompassed changes in luminance and color. Second, items of "central interest" using Rensink et al.'s terms do not exactly correspond to meaningfulness as defined here. For example, if the car in the center of a picture changed color, this would probably be of central interest in Rensink's terms, but of little "meaning" to the task of driving.

Finally, the finding that older adults had more difficulty detecting change under most circumstances adds a new dimension to the present literature on change detection. It is interesting to note that older and younger adults show differences in detecting changes (i.e., that meaningfulness had very little influence on older adult change detection performance compared with younger adults), but not altogether unsurprising given other findings for age-related differences on various visual search tasks (e.g., Humphrey & Kramer, 1997; Rogers & Fisk, 1991; Gilmore, Tobias & Royer, 1985). The abundance of findings for qualitative (as well as quantitative) differences for older adults on a variety of visual search tasks implies that visual search for change in a simulated saccade paradigm may exhibit age-related differences as well.

Attentional Breadth and Change Detection

A strong correlation between breadth of attention and change detection was found, such that a smaller FFOV corresponded to slower change detection. This finding strengthens the claim for a relationship between efficiency of change detection and attention (Rensink et al., 1997). Furthermore, the results suggest that a particular aspect of attention, that is the breadth of attention, plays an important role in perceptual change detection, presumably by reducing the number of attentional samples required to detect a change.

In summary, it appears that visual attention plays an important role in detecting change since individual differences in breadth of attention reliably correlated with perceptual change detection. Furthermore, salient scene characteristics were more responsible for driving attention to change than meaningful change characteristics, especially for older adults. These results raise a number of important issues, which will be considered in the following section.

ADDITIONAL ISSUES RAISED BY THE RESULTS OF EXPERIMENT 1

Experiment 1 is an attempt at examining important factors in perceptual change detection performance. The primary finding was that attentional breadth played a role in perceptual change detection, although this does not preclude the role of other factors, such as working memory and perceptual speed, and does not rule out the possibility that change may be detected without requiring explicit awareness. In other words, attention may be linked to explicit awareness of the change, but change detection may also be mediated by other factors and perhaps change can be detected implicitly. In addition, the relevance (or meaningfulness) of a change to the task of driving was not found to have a strong influence on older adults' ability to detect change in the detailed driving scenes used in Experiment 1. Thus, the issue remains as to how to create a sufficiently meaningful context for all participants in order to increase the likelihood of detecting meaningful change.

The following section explores these issues, starting with a discussion of intrinsic factors (i.e., working memory, inhibition and perceptual speed) that have the potential to account for differences in perceptual change detection among individuals, independently or in conjunction with attention. Next, extrinsic influences on change detection are explored, specifically focusing on the role of driving relevance and the means by which to increase the meaningfulness of the driving context. Finally, the discussion turns to the possibility that change may be detected without attention, and potential real-world consequences of the failure to detect change.

Individual Differences in Other Intrinsic Factors

Working Memory

While Experiment 1 suggests a relationship exists between attentional breadth and perceptual change detection, the possibility remains that attention may be necessary but not sufficient for detection of some changes (i.e., Levin & Simons, 1997). One construct to consider is the role of memory, given the assumption that successful scanning for change requires memory for locations and objects previously examined (although it has been recently asserted that visual search does not utilize memory, as will be discussed below). Accordingly, individuals with better object-location memory, and perhaps other varieties of memory, should be able to scan scenes more efficiently and detect change more rapidly.

Central to the idea that memory is involved in perceptual change detection is the notion that a representation of the scene does indeed exist over successive fixations on the scene. As discussed previously, evidence in transsaccadic memory suggests that the nature of scene representations is not detailed (McConkie & Currie, 1995; Irwin & Gordon, 1998; Henderson & Hollingworth, 1999b; Currie et al., in press). Although these findings cast doubt on the existence of a detailed internal representation, they

do not eliminate the possibility that *any* representation exists.[2] In fact, such a representation may be limited to only a few objects and the target of the saccade may play an important role (Irwin, 1996; Irwin & Gordon, 1998; Currie et al., in press).

In contrast to findings for a limited scene representation in the transsaccadic literature, recent research in visual search asserts that successful visual scanning does not maintain a representation for locations and objects previously examined. Instead, it is suggested that visual search is "amnesic" and representations do not last beyond their visual persistence (Horowitz & Wolfe, 1998, 1999). The claim of amnesic search is based on evidence that visual search for a target embedded in stimuli that shift location in a display is as effective as search for a target embedded in stimuli that remain stable. In other words, because memory could have benefited search in a stable display but didn't, Horowitz and Wolfe (1998) claim that "visual search has no memory". This assertion has been challenged on several accounts, such as the post-display mask used may have disrupted memory location (Scheier, Khurana, Itti, Koch & Shimojo, 1999) and speed-accuracy issues (Klein, Shore, MacInnes, Matheson & Christie, 1998). In particular, it does not address previously observed results involving memory (e.g., transsaccadic change detection is indeed difficult, though not impossible, McConkie & Currie, 1996, Irwin, 1996; target detection is enhanced for previously shown but implicitly learned configurations, Chun & Jiang, 1998; priming of pop-out targets lasts over 10 subsequent trials, McPeek, Maljkovic & Nakayama, 1999). Finally, the amnesic search claim could also be challenged as a generalization about human performance based on non-realistic scenes (which will be addressed in the current study).

At this point, a reasonable conclusion is that Horowitz and Wolfe's (1998, 1999) findings are inconclusive as to the existence of amnesic search (Backer & Peral, 1999). Nonetheless, there are potential implications for the current study. The existence of a scene representation, even if sparse, would support the possibility that working memory could play a role in visual search for change and efficient scanning of items and locations in a scene. On the other hand, if the representation is non-existent, then it is much less likely that memory could support efficient scanning of locations and objects and therefore, it would not have much effect on change detection performance. Regardless, considering memory as a potential mediator in change detection performance will not be diminished by Horowitz and Wolfe's finding.

Psychometric measures of memory have not been extensively used to predict performance on visual search tasks. Most likely, measures of memory would not be sensitive to typical visual search response times on the order of milliseconds. Psychometric measures of memory have been used to predict performance on other tasks, particularly in the aging literature. For example, one study assessed whether individual differences in one aspect of memory (i.e., working memory, WM) could account for memory for

[2] Interestingly, Noë, Pessoa and Thompson (2000) make the philosophical argument that a detailed internal representation does not exist, although they admit that the hypothesis cannot be eliminated on the basis of the current evidence. They do not consider the possibility of an intermediate, less detailed representation, instead they favor the existence of an external representation.

changes to objects in line drawings of organized and unorganized scenes (Frieske & Park, 1993). A computation span task assessed working memory by having older and younger adults solve simple arithmetic problems while concurrently remembering the second number in the equation for a later recall test. During the experimental task, observers viewed 24 pictures for 8 seconds each, followed by a 2-minute break, and then responded to 24 test pictures, identifying those that were changed and those that remained the same. Subjects were informed in advance that the possible types of changes included location and identity changes. The WM measure alone accounted for a significant amount of variance (15-17%), independent of age, except when the change consisted of a relocation in an organized scene (in which case it accounted for less than 5% of the variance). Frieske and Park (1993) thus conclude that "working memory is useful but is not a complete account of age differences in scene memory" (p. 329). Moreover, their results suggest that WM differentially accounts for age-related variance in memory for scene change as a function of change type. Finally, it is interesting to note that the task of successfully recognizing a scene (as in Frieske & Park, 1993) does not necessarily require access to details that would be required for successful performance on a perceptual change detection task.

The notion that working memory is not a unitary construct has been supported by other research, most notably Baddeley and Hitch (1974, 1994). They have proposed a model of working memory consisting of three components: a visuospatial sketchpad, phonological loop and a central executive (Baddeley & Hitch 1974; 1994). The phonological loop holds and manipulates temporal, verbal information for up to 2 seconds, unless a subvocal rehearsal process is invoked to maintain it. The visuospatial sketchpad maintains and manipulates representations of objects, locations and their interrelations. Finally, the central executive is concerned with coordinating multiple on-going processing and manipulating attentional control (Baddeley & Hitch 1974; 1994). The functioning of the central executive is measured by tests such as the backward digit span, reading span and computational complexity (e.g., Daneman & Carpenter, 1980; Verhaeghen, Kliegl & Mayr, 1997).

Given that memory may be reasonably viewed as a multi-faceted construct, consideration of other varieties of memory detection is warranted (e.g., spatial and verbal memory). Spatial ability will first be briefly considered. Spatial ability can be defined as the ability to reason about visual scenes (Pellegrino & Hunt, 1991) or it can be defined in terms of its components (i.e., spatial relations, spatial orientation, visualization; Lohman, 1979). It seems self-evident that a change affecting an object's location or presence could be characterized by a measure of memory for spatial or object spatial relations. Unfortunately, research on the topic is sparse. One study found evidence that spatial ability related to individual differences in a stimulus discriminability response time tasks (Dupree & Wickens, 1982). Another study related spatial ability (i.e., flexibility of closure, spatial scanning and spatial visualization) to search for target information embedded in a hierarchy of computer text menus. Vicente, Hayes and Williges (1987) found that measures of spatial ability significantly related to overall search time and were more predictive of this

task than the verbal abilities assessed (although verbal ability measured by reading rate, vocabulary and comprehension, was also significantly related).

Another consideration for perceptual change detection is verbal memory, given that observers could employ a verbal strategy while scanning scenes (e.g., instead of encoding the visual aspects of a giant yellow M on a sign, observers might instead encode "McDonalds"). In one study, recognition memory for pictures was supported by both verbal and visual codes (Snodgrass, Wasser, Finkelstein, & Goldberg, 1974). Also, verbal ability was a significant predictor of search for information in the computer menu task above (Vicente et al., 1987).

In addition to considering multiple aspects of working memory, age-related differences on each memory component will be a concern in characterizing individual differences in perceptual change detection performance. In fact, age-related decline in WM is related to age differences in performance on some complex tasks (Salthouse, 1992; Kail, 1995). Age differences in memory may also be qualitative in nature, such the ability to recall details of central interest. For example, older adults more frequently failed to report the weapon carried by an assailant in a simulated assault, while younger adults were significantly better in recalling this detail (Yarmey, Jones & Rashid, 1984). This would be consistent with the finding in Experiment 1 where older adults were less sensitive (i.e., slower to respond) to change meaningfulness than younger adults.

Though older observers routinely exhibit poorer memory than younger observers on a variety of tasks, this is certainly not the case for all aspects of memory. Indeed, indirect measures of memory have shown that implicit memory may be spared in older adults (e.g., Light & Singh, 1987; Light & La Voie, 1993; Mitchell, 1993). Implicit measures of picture memory, such as facilitation in picture naming or object decision, have shown negligible age differences in contrast to large age differences on explicit measures (e.g., recognition accuracy; Mitchell, 1993).

Thus, the ability to remember objects and their locations in a scene should relate to the ability to efficiently search a scene and detect changes to objects. Moreover, the relationship between memory and perceptual change detection will most likely differ across the various aspects of working memory (e.g., executive function, visuo-spatial WM, verbal WM). Finally, the role of memory in perceptual change detection will reflect changes with older age. Accordingly, individuals with better object-location memory, and perhaps other varieties of memory, should be able to scan scenes more efficiently and detect change more rapidly.

Perceptual Speed

Independent from memory, perceptual speed has the potential to account for perceptual change detection performance due to the nature of the task (i.e., it requires observers to respond quickly upon detecting the change). Perceptual speed (i.e., response time on a simple discrimination or psychomotor

task) is often claimed to be a fundamental cognitive construct underlying complex cognitive task performance (or complex skill acquisition; see Ackerman, 1990). Salthouse (1988, 1992) claims it is particularly effective in characterizing age-related decrements in cognitive performance, sometimes accounting for as much as 93% of the variance in performance on complex laboratory tasks (see also Kail & Salthouse, 1994). Moreover, measures of perceptual speed often account for a much greater portion of the variance than other possible mechanisms of age-related decline, although it is not the only fundamental construct.

It is important to recognize that perceptual speed may also subserve other factors considered here. For example, simple processing speed is related to performance on working memory tasks, specifically those assessing executive function (e.g., computation span, listening span, digit span; Salthouse & Babcock, 1991). Also, a computer simulation pitting inhibitory processes against speed of processing suggested that a decline in inhibitory processing could be accounted for by reduced processing speed (Lindfield & Wingfield, 1999). Thus, the relationship between perceptual speed and other factors will be an important consideration in this study.

A drawback in the use of perceptual speed for interpreting results is that response time measures cannot isolate the independent contributions of the sensory, cognitive, response-selection and execution aspects of performance. Additionally, perceptual speed lacks a clearly specified underlying mechanism and thus limits its utility in interpreting results. Nonetheless, perceptual speed is a compelling means of characterizing cognitive performance, especially when age differences emerge.

<u>Inhibition of Irrelevant Information</u>

Given the extent to which the trials (i.e., changes) in a change blindness paradigm are unrelated and novel (i.e., not repeated), then knowledge of a specific change in one trial should be irrelevant for the detection of change in a subsequent trials. Thus, the ability to inhibit irrelevant information (about previous changes) was also considered as a potential mediator in perceptual change detection performance.

One approach to assessing the ability to inhibit irrelevant information is via proactive interference (PI) tasks. PI tasks examine the extent to which dimensions of the stimulus are encoded (unintentionally) and influence performance on short-term memory tasks (Wickens, Born & Allen, 1963; Wickens 1970). For example, the participant is presented with several items (e.g., pictures) which, after a brief delay, must be recalled. Recall performance declines over successive trials when the items share some attribute (e.g., orientation), although the specific stimulus items presented in each trial are unique. The decrease over trials has been interpreted as a build-up of PI (Wickens et al., 1963; Wickens 1970).

Of particular interest are findings of PI build-up with pictorial stimuli and PI build-up with respect to advanced age. Pictorial stimuli are not extensively used in PI paradigms, perhaps because they are generally recalled with greater ease than auditory stimuli. Nonetheless, it has been demonstrated that

buildup of PI can occur over repeated presentations of categorically similar pictorial stimuli. Examples of pictorial stimuli include black-and-white photos, color photos, and line drawings of everyday objects.

In contrast, a great deal of research and controversy has dwelled on the issue of age and whether older adults are more susceptible to buildup of proactive interference. On the one hand, some researchers find a reliable age difference in susceptibility to PI (e.g., Schonfield, Davidson, & Jones, 1983; Hasher & Zacks, 1988). On the other, age differences in PI susceptibility are not always confirmed and consequently, it may not be as general a phenomenon as once thought (e.g., Puckett & Lawson, 1989; Pershad, 1979; Kramer, Humphrey, Larish & Logan, 1995), Some of the pertinent issues seem to include the initial memory spans of participants, the range of ages compared (e.g., the distinction was tenuous in one study, with the young aged 20-40 years, the old aged 41-70 years; Pershad, 1979), the number of stimuli presented and the influence of rehearsal during delay (Tyrrell et al., 1981). Because these effects in PI buildup are only tangentially relevant to the present research, their influences will be minimized in order to get a straightforward measure of PI buildup for participants of all ages.

One interesting combination of pictorial stimuli and advanced age in a study involved a facial recognition memory task (Flicker, Ferris, Crook, & Bartus, 1989). Eight black and white photographs of faces were repeatedly shown to 16 young Ss (aged 18-30 yrs) and 28 elderly adults (aged 63-83 yrs). Two non-repeating faces were included as catch trials. Using signal detection analysis, the researchers found that although recognition sensitivity (d') increased for repeated faces over the course of the experiment, it was accompanied by a significant increase in false positives in the latter half of the experiment for older adults. The authors interpreted this false positive effect as the result of PI buildup. Fatigue effects were refuted since, over the course of the experiment, miss rates were unchanged and response times speeded up. Because PI appears to buildup over repetitions of the same pictures, it is also plausible that PI might buildup over consecutive trials of contextually similar, though unrepeated, pictures.

Thus, in the change detection paradigm, it is beneficial for observers to look at each new scene with a "fresh" perspective, while inhibiting information from the previous, now irrelevant, picture (i.e., the previous change). Yet, PI buildup may be evident if a shared attribute of the scenes, such as the driving context, increasingly interferes with change detection performance.

Reviewing the Influence of Change Meaningfulness

Consider that Experiment 1 showed a benefit for driving relevance (i.e., meaningfulness) in perceiving scene changes. If knowledge of a task (e.g., driving) leads observers to only look where they expect to find changes or useful information (e.g., Sarter & Woods, 1997), then the meaningfulness benefit is not surprising, given that Experiment 1 set the stage for a driving task by including only driving-related scenes (from the driver's perspective behind the wheel), and a driver behavior questionnaire was completed before participants began the perceptual change detection task. Yet, the driving relevance benefit was only

evident in younger adults' performance, suggesting that older adults were not as engaged in the driving task and consequently, were not as sensitive to driving relevant aspects of the scene. Given that the driving relevance of the extrinsic context in Experiment 1 had an inconsistent influence on the detection of meaningful changes, the means by which to increase the engagement in the driving context, especially for older adults, is explored in this section.

Much of the relevant literature comes from work in virtual environments (i.e., virtual reality). Visual cues, in particular, have a profound effect on the participant's sense of engagement or presence in a virtual environment, one of the most important being motion (Rinalducci, 1996; see also Wickens & Baker, 1995). In fact, observers report stronger feelings of presence in a virtual environment in which objects appear to move relative to them (Witmer & Singer, 1998). One explanation for motion's powerful influence on engagement may be that it increases the coherence between the observer's knowledge about the real world and what is being viewed (Witmer & Singer, 1998). Additionally, motion obligates observers to repeatedly update and even anticipate an object's trajectory, as supported by evidence of representational momentum, in which observers anticipate the continued motion of an object, after it has disappeared (i.e., Finke & Freyd, 1985; Freyd, 1987). Finally, object motion may be engaging because observers cannot ignore it. Research reveals that the motion of a target "pops out" (i.e., supports parallel search) when displayed among stationary objects (Dick, Ullman & Sagi, 1987; McLeod, Driver & Crisp, 1988; Nakayama & Silverman, 1986).

The degree to which motion will enhance engagement varies, especially in virtual worlds. For example, when motion is accompanied by lags in screen updates or is inconsistent with the laws of physics, the observer's sense of engagement is reduced (Slater & Usoh, 1993). It is also important to consider that the perception of motion depends on the ability to perceive minimal cues such as global optical flow rate, optical edge rate, and discontinuities in optical flow (Rinalducci, 1996), often difficult to create in artificial worlds which may lack adequate texture or detail. These effects must be addressed in artificial worlds, but are minimized in other media such as real-time video.

Another effective visual cue for increasing engagement is the size of the field of view (FOV) or the visual angle subtended by the display (distinct from the FFOV). Typically, broader FOVs correspond to a greater sense of engagement. For example, Prothero and Hoffman (1995) compared two display breadths, 60 and 105 degrees visual angle, and found that observers reported higher levels of engagement for the wider FOV. Similarly, the geometric field of view (i.e., GFOV) impacts the observer's level of engagement such that larger angles correspond to greater engagement (Hendrix & Barfield, 1996). The geometric field of view refers to the angle between the center of the projection to the edges of the observer's viewpoint (Hendrix & Barfield, 1996). For example, a small GFOV would be analogous to a zoom function on a camera. A limitation in both of these studies is that engagement was not measured at larger angles, but a reasonable inference is that an exceedingly large angle would negatively impact engagement.

Additional means of increasing one's sense of presence include but are not limited to: multi-modal feedback, pictorial fidelity and minimizing extraneous distractions. The addition of auditory feedback, for example, in a virtual environment enhances presence by providing redundant information about the environment and more closely mimics the feedback inherently received in the real world (Wickens & Baker, 1995; Witmer & Singer, 1998). The degree to which visual features in the virtual environment conform to visual features in the real environment (i.e., pictorial fidelity; Rinalducci, 1996) can also enhance engagement; however, pictorial fidelity may have less of an influence on engagement compared with other characteristics (Welch, Blackmon, Liu, Mellers & Stark, 1996). Finally, the presence one experiences in a virtual world is adversely affected by a variety of distracting events occurring in the real world, such as noise (Witmer & Singer, 1998).

The presence of the any or all of the above characteristics will not ensure that an observer is engaged in a scene, but is also dependent on the extent that these characteristics are perceived. Nonetheless, they serve to collectively enhance the realism of the environment, and consequently, one's sense of engagement. Furthermore, these cues have only been shown to enhance engagement in younger observers and the potential exists for older observers to be less sensitive (or insensitive) to them, especially given findings that older people are generally less comfortable interacting with computers (Czaja & Sharit, 1998) and that a relationship exists between the degree of immersion and age (Bangay & Preston, 1998). The relative effectiveness of these characteristics may become apparent in responses to a questionnaire. For example, Witmer and Singer (1998) developed two questionnaires tapping individual differences in the potential to feel engaged and how much a particular technology engages individuals.

In summary, the literature points out numerous characteristics that could increase one's sense of engagement in the environment (e.g., motion, wider field-of-view), which could also increase the likelihood of detecting task relevant or meaningful changes, especially for younger adults. Yet, one must be cautioned that even if these factors enhance a sense of engagement in older adults, it may still not affect the detection of meaningful changes in perceptual change detection..

Change Representation without Attention

The hypothesis that attention is necessary for perceivers to detect change was supported by a strong correlation between attentional breadth and perceptual change detection latency in Experiment 1. However, recent research suggests that change may be represented without observer awareness (Fernandez-Duque & Thornton, 2000; Rensink, 1998; Hayhoe et al., 1998). Assuming that awareness is one means by which to measure attention, then these findings additionally imply that change may be represented without observer attention.

Fernandez-Duque and Thornton (2000) found that observers selected targets (i.e., changed items) significantly above chance performance, even though they reported to have no awareness of the change. In

this experiment, a 250ms blank screen interrupted the presentation of two 250ms displays, comprised of 16 bars arranged in four rows and columns. On the second presentation of the display, one of the 16 bars had been rotated. Following the last display presentation, observers were instructed to select the bar location where the change occurred in a two alternative forced choice task and then report whether or not they had seen the change. For trials in which the observer reported being unaware of the change, accuracy was significantly different from chance and robust across observers (demonstrated in over three-quarters of observers). At the same time, accuracy on these trials was much lower than trials in which the observer reported being aware of the change (i.e., 55% and 85% for unaware and aware responses, respectively).

It is possible that response criterion may at least partially account for these results, given that false alarm rates could not be analyzed. In other words, greater responding would result in higher correct detections *and* false alarms. Yet, the differences between liberal and conservative responding go some way in addressing this issue. Moreover, the findings are consistent with other results in the literature, such as those reported by Rensink (1998), in which approximately one-third of observers claimed to "sense" a change in the display before they reported actually "seeing" it. In another study, observers grossly underestimated the occurrence of task-relevant changes occurring during a saccadic eye movement (Hayhoe et al., 1998).

Verbal underreporting of visual processing has also been reported in patients with simultanagnosia. Despite having visual abilities well within the normal range, these patients report objects disappearing after being fixated (Rizzo & Hurtig 1987). Examination of scan patterns revealed the target was fixated the entire time it disappeared. In other words, observers may be unaware of the image before them, but their eye movements reflect some processing of the image. Normal people also report objects fading from conscious awareness while fixating in the cases of ocular paralysis (Stevens et al., 1976).

Thus, the role of attention in our ability to detect change in scenes is unsettled. On the one hand, focused attention may to be required when the change detection task requires a precise, verbal response, as in the saccade-contingent and simulated saccade-contingent studies. On the other, there is the potential for change representation to exist without attention or the observer's awareness. Measures of attention, such as eye movements, could be informative as to the nature of our representation for change and will be examined in the next section.

Eye Movements as an Implicit Measure of Attention

There are three advantages in measuring eye movements as an indirect measure of attention during a perceptual change detection task. One is that it does not interfere with the ongoing visual search. The second is that it is not dependent on explicit report, unlike most responses in change blindness paradigms, and thus it may provide a unique indication of implicit change detection. Thirdly, it may provide an indication of the locus of attention, given the eye's fixation point. As such, it will provide an interesting

means to further examine the "attention-only" hypothesis in perceptual change detection. The previously discussed saccade-contingent change studies measured eye movements during perceptual change detection, though only two of which reported the fixation position relative to the likelihood of change detection.

Eye position is a useful indicator of attention because attention appears to precede a saccade to a given location (Hoffman & Subramaniam, 1995; Kowler et al., 1995). In fact, some go so far as to suggest that the "execution of a saccadic program may involve an obligatory attentional shift" (Klein, Kingstone & Pontefract, 1992, p. 62; see also Irwin & Gordon, 1998). This claim is strengthened by neurophysiological data, showing that common areas of cortex exhibit neuron activity during eye movements, as well as for shifts in attention independent of eye movements (Andersen & Gnadt, 1989; Colby & Duhamel, 1996; Corbetta, Miezin, Shulman, & Petersen, 1993). It should be noted that attention can also be deployed independent of eye movements in some simple discrimination tasks (Posner, 1980), but this is not efficient for scanning more complex environments (as in the real-world scenes used in Experiment 1) compared with conducting a series of saccades (He & Kowler, 1992).

Ideally, the link between where the eyes move and where the mind attends would be preserved even when the eyes were stationary (i.e., the eye-mind hypothesis). Unfortunately, two findings suggest that fixation location is not a precise indicator of the locus of attention. The first finding, parafoveal preview benefits, suggests that information is extracted (i.e., attended) from objects or locations that are not directly fixated (Rayner, 1983; Rayner & Pollatsek, 1987). For example, Fox, Merwin, Marsh, McConkie and Kramer (1996) found that removing information from flight instruments peripheral to fixation greatly reduced pilot performance compared to intact peripheral information. Nelson and Loftus (1980) also found that observers could use objects located beyond 2.6° from fixation to recognize scenes. Specific types of change (i.e., deletions) can be detected with reasonable accuracy from as far as 7° away (Henderson & Hollingworth, 1999b), or greater than 2.6° away for some observers in a flicker paradigm (Hollingworth & Henderson, 1998). Although the latter study found that the vast majority of changes were detected foveally, as opposed to parafoveally, it is evident that information extraction is not limited to the immediate fixation location. Thus, it is reasonable to assume that attention is not limited to this region either (presumably this area would be designated by one's attentional breadth).

The second finding is more problematic for the eye-mind hypothesis, indicating many occasions when objects at fixation or within foveal vision are not noticed by observers. The classic study by Neisser and Becklen (1975) demonstrates that observers have no trouble selecting one of two superimposed games at fixation, but when required to attend to both games at once, their performance declined. More recently, findings of "inattentional blindness" indicate that a perceptible object stimulus appearing at fixation or in the near periphery can be completely missed by observers engaged in a secondary task (e.g., Rock, Linnett, Grant & Mack, 1992; Mack & Rock, 1998). In an interesting combination of these two approaches, Simons

and Chabris (1999) reported that observers often failed to report an unexpected moving object appearing at the same location as an ongoing, attended event. It is evident from these studies that observers are not necessarily aware of events occurring at an attended spatial location.

Nonetheless, behavior can be influenced by events of which individuals are unaware, suggesting some representation of the event exists. Moore and Egeth (1997) demonstrated that observers making line length judgments were systematically influenced by patterns in the background that they did not detect or recognize. Eye movement behavior can also be influenced by events of which individuals are unaware. In the "eye-movement based memory effect" (Althoff & Cohen, 1998; Althoff, 1998), the eye patterns of observers with previous exposure to faces reflect their greater familiarity with the stimuli, and hence, are less constrained by stereotypical scan patterns employed with novel stimuli. In another study, familiarity with scenes was shown to affect eye fixations, such that the eyes were drawn to areas in the pictures that underwent change, despite the observers inability to explicitly report the change (Ryan, Althoff, Whitlow & Cohen, in press). For older adults, eye movement measures of implicit or procedural memory may be especially useful for gaining information about visual processing, given their tendency to have poorer explicit memory (Mitchell, 1993).

All in all, attention is not perfect at fixation and is not limited to the fixation location, yet the fact that undetected events can influence behavior, suggests that these undetected events are processed. Eye movements will be important in determining what is processed, although the typical measures of examining visual scanning of scenes (i.e., fixation duration and location) should be considered in conjunction with other measures of scanning behavior.

The issue then arises concerning the selection of appropriate components of eye movement behavior beyond the standard fixation duration and location. Indeed, diverse components may reflect aspects of the observer's scanning behavior (see Henderson et al., 1999). Additional measures of eye movement behavior include: total fixation duration, total fixation count, average fixation duration and the distribution of fixation durations over the entire scene. When a specific region in a scene is of interest (e.g., a changed object in perceptual change detection), additional measures to consider are the fixation density within a given (target) region, the probability of fixating a target region as a function of the fixation, the number of fixations on a scene prior to first fixation in the target region, the amplitude of the initial saccade to the target, first pass gaze duration, and so on (Henderson et al., 1999).

Finally, in associating eye movements with the previously discussed measure of attention (i.e., FFOV), a smaller FFOV should require more eye movements to locate and identify targets, especially peripheral ones. Indeed, Scialfa et al. (1994) reported that older observers had more difficulty in locating peripheral targets (i.e., a restricted FFOV) and made more eye movements, especially for eccentric targets. This suggests that the size of the FFOV determines number of saccades and consequently affects search time (Scialfa et al., 1994).

In summary, eye movement data should be useful for examining perceptual change detection for two reasons. First, they are an indicator of visual processing even in the absence of attention and thus will be useful in examining the hypothesis that change may be represented without awareness. Additionally, they will indicate the position of the eye fixation relative to the position of the changed object, and should demonstrate the utility of measuring attentional breadth, presuming that both positions fall within the defined area.

Summary

The findings in the literature support several conclusions. First, additional factors, such as working memory, inhibition and perceptual speed, may play a role in the relationship found in Experiment 1 between attention and perceptual change detection. Second, motion, sound and an increased field of view may be employed as means to increase the meaningfulness of scenes and hence, should increase the likelihood of detecting task relevant or meaningful changes. Third, attention and awareness may not always be required for the development of representation of scenes and perceptual change. Finally, eye movements may be useful to study visual processing without awareness. These issues were addressed in Experiment 2.

EXPERIMENT 2: MULTIPLE MEDIATORS OF CHANGE DETECTION PERFORMANCE

The goals of Experiment 2 were to investigate the influence of factors that mediated change detection performance. Psychometric measures of memory, inhibition and perceptual speed were examined along with attention for the degree to which they related to performance on the perceptual change detection task. Additionally, the influence of scene relevance or meaning on change detection performance was examined by increasing the importance of the context of driving in scenes. Finally, given previous findings that representations of scenes can be maintained without observers' awareness, eye movement behaviors were recorded as an implicit means to examine the development of change representations. Again, both young and old adults participated in the study, in order to broaden the range of individual differences.

Hypotheses

Three fundamental hypotheses were examined. The first hypothesis was that attention will play a role in change detection performance, along with memory, inhibition and perceptual speed abilities. This hypothesis was based on the finding that attention may be necessary but not sufficient for change detection (as in Levin & Simons, 1997) and the assumption that successful change detection relies on a memory representation for areas and objects scanned (e.g., Irwin, 1996; Ryan et al., in press). Hierarchical regressions performed on the change detection response time data were expected to show that after removing the variance explained by individual differences in attentional breadth, a significant portion of the remaining RT variance would be accounted for by individuals' performance on working memory, inhibition and perceptual speed tasks. Finally, age was expected to relate to change detection performance, with older age corresponding to slower detection times, consistent with results of Experiment 1. Age was not considered as a *predictor* of performance on change detection, rather its relationship with change detection RT is the result of its relationship with the other measures of theoretical constructs. Hence, individual differences in performance on the psychometric tasks were predicted to moderate this age-related variance in change detection RT, based on evidence that older adults, compared with younger adults, have a narrower breadth of attention, smaller working memory spans, slower perceptual processing and a decreased ability to inhibit irrelevant information.

The second major hypothesis was that the effect of change meaningfulness on performance would be moderated by several factors. First, consistent with findings in Experiment 1, it was hypothesized that change meaningfulness would interact with change salience and the age of the observer. Second, it was hypothesized that increasing the context of scenes (via realistic motion and sound) would positively influence perceptual change detection for changes of high meaningfulness. This hypothesis was based on the assumption that automobile background noise is more reflective of the true driving environment and, in conjunction with the natural motion of other objects in the scene relative to the viewer, would increase the

observer's engagement in the driving scenes (Wickens & Baker, 1995; Witmer & Singer, 1998). The increased engagement in the scenes was expected to direct the observers' attention to meaningful (driving relevant) changes in the scene, relative to observers viewing a less engaging scene preview (or none at all). The detection of low meaning changes should be unaffected by the observers' engagement in the scene context. While it was predicted that the movie would enhance a sense of engagement in both age groups, it was uncertain the extent to which the manipulation would be effective for older people given that they are generally less comfortable interacting with computers (Czaja & Sharit, 1998) and the success of manipulating engagement has not been established in the literature with an older population.

The third hypothesis examined in this study was that eye movement behavior would reflect the observers' representation for change. This was based on previous findings that suggest that eye movements are an indirect means of indicating visual processing of a scene of which the observer is unaware. Indices of viewing frequency and duration, such as fixations and fixation durations, were anticipated to reflect differences in the visual processing of a changed location compared with the processing of that location when it is not undergoing change. Additionally, attentional breadth (i.e., FFOV) was expected to correspond with eye movement behaviors in the scene, such as number of dwells and saccadic amplitude. For example, those with larger FFOVs should typically be able to make longer saccades and fewer dwells than those with smaller FFOVs, assuming that items in the display are dispersely located.

Method

Participants

Of the 169 adults scheduled to participate in the experiment, 38 were eliminated from the study due to an inability to track their eyes (9 of which were young adults). Sixty-six of the remaining 131 participants were young adults (mean = 20.9 years), 19 of whom were men. The 65 older adults (mean = 68.3 years) consisted of 21 men and 44 women. Participants met the following minimum criteria: corrected visual acuity better than 20/40; possess a valid driver's license; at least 2 years driving experience; at least 25 miles driven on average each month. Younger adults were recruited from the University of Illinois, whereas older adults were recruited from the local community. Screening was accomplished for adverse health factors that would impact performance on the experimental tasks (e.g., head injuries resulting in memory or attentional loss, use of psycho-therapeutic medications or beta-blocking agents). Summary demographic information is reported in Appendix C. It should be noted that both older and younger adults reported similar levels of education and equally high participation in fitness activities. The majority of respondents from both age groups reported good to excellent health and fair to excellent memory ability, compared with same aged peers. A much higher proportion of older adults reported use of medications (91%), compared with younger adults (48%).

Apparatus

The stimuli were presented on a virtual reality system, the ImmersaDesk, a vertical projection based display (48" x 66") controlled by a Dell computer, which also recorded manual responses. Eye movements were monitored using an Applied Science Laboratories (ASL) eye and head tracker (Model 501), mounted on the participant's head. The ASL eye tracker detects eye movements up to 50° horizontally and 35° vertically by highlighting the pupil (i.e., "bright pupil" method) and then calculating the difference between the diameter of the pupil and an infrared reflection on the cornea. When head movements are accounted for, the eye/head tracker combination measures a field of unlimited size. Participants were seated on a raised platform approximately 33 inches from the display, such that the display subtended 90° horizontally, 72° vertically, and their eyes fixated the center of the display when staring straight ahead. The calibration process is discussed below. It should be noted that a slight bias in the eye tracker output was detected and accounted for in the data (see "Eye Movement Behavior During Baseline", p. 65).

Perceptual Change Detection

Observers initially participated in the perceptual change detection task, lasting approximately 2 hours. As in Experiment 1, the perceptual change detection task was modeled after Rensink et al.'s (1997) flicker paradigm, with gray blank fields appearing between successive photographs of original and modified driving scenes. Three departures from the methodology employed in Experiment 1 should be noted. First, the succession of the original and modified photographs alternated after *every* blank screen (i.e., A, A', A, A'), rather than every *other* blank screen (i.e., A, A, A', A'). This modification was introduced in order to increase the likelihood of detecting a change. Another departure was the use of equipment to monitor eye position (see above). Finally, one of three preview conditions was added to the task, prior to the onset of the flicker sequence (see Figure 10).

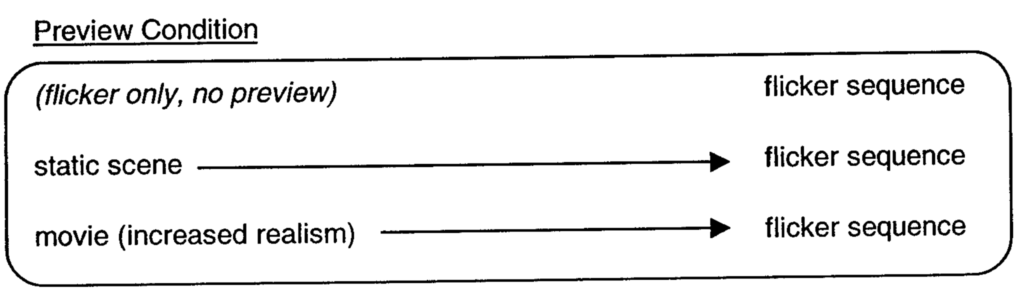

Figure 10. Preview conditions in perceptual change detection task.

In the flicker only condition, no preview of stimuli is presented; observers viewed the flicker sequence as in Experiment 1 and had up to 60 seconds to detect a change to a single object in each picture. In the static scene condition, observers viewed the first photograph of the flicker sequence for 15 seconds, immediately followed by the onset of the flicker sequence. Eye behavior data collected during the static 15-

second preview served as the non-changing baseline for comparison with eye data collected during the flicker sequence (see p. 58 for more detail). The movie (i.e., increased realism) condition presented a 15-second movie clip of a driving film (with background sound), prior to the onset of the flicker sequence. The driving clip was taken from the driver's perspective of a moving vehicle, which ended exactly at the first scene in the flicker sequence.

Stimuli

The stimuli consisted of 85 naturalistic scenes from the Chicago, IL, area. The scenes, videos and audio segments were taken from the same original footage (Hi-8 film), videotaped in a single day using a VHS camcorder mounted on a tripod in a moving vehicle. Images were later digitized using Avid for Macintosh at 70 AVR compression, with picture quality set at 640X480 pixels (and sample audio rate at 22.050kHz for video segments). Videos were further compressed into QuickTime movies (AppleVideo Codec, 30 frames/sec) using MediaCleaner Pro 3.1 for use on IBM compatible machines.

The last frame of each 15-second video segment was extracted for use as the original image in the flicker sequence, and was later modified using Adobe PhotoShop. An image change involved a transformation of a single object's color, location or presence in the scene and was categorized according to meaningfulness and salience (see below). Brief descriptions of the 85 scene changes are provided in Appendix E. An effort was made to ensure that scenes (and video clips) were not repeated and that changes were as unique as possible. Note that 8 of the changes were located in the center of the picture, 77 were located in the periphery, thus change eccentricity was not analyzed. Most of the items selected for change were stationary objects in the videos, but a small subset were moving in the video segments of the increased realism condition. Previous research indicates that changes to such objects might be more readily detected in the increased realism condition due to prominence of motion against a static background (Dick et al., 1987; McLeod et al, 1988; Nakayama & Silverman, 1986).

Procedure

The experiment began with ensuring the eye monitoring equipment was properly calibrated to the individual. With their chins temporarily resting on a chinrest, subjects were instructed to gaze at 9 fixation points in succession while eye positions were recorded. The 9 numbers of the calibration screen were assembled into 3 rows of 3 numbers each, with the number 5 at the absolute center of the display. The entire 3X3 array subtended 25° horizontally and 25° vertically. Once the equipment was satisfactorily calibrated for the individual at these 9 points, measurements of the peripheral regions of the display were then verified by having the subjects turn their heads and look at each corner of the display while the experimenter noted the output. If the value was within tolerated limits (i.e., within 1 degree of the expected value), then a final measurement was taken while the subject gazed at a 5X5 array of plus signs spanning the

entire 90°X72° display, which required head movements. That final measurement served as a post-hoc check on the integrity of the calibration. Calibration was repeated every 20 trials as a minimum, or more often, if required. Following calibration, the trial sequence could begin (see Figure 11 below).

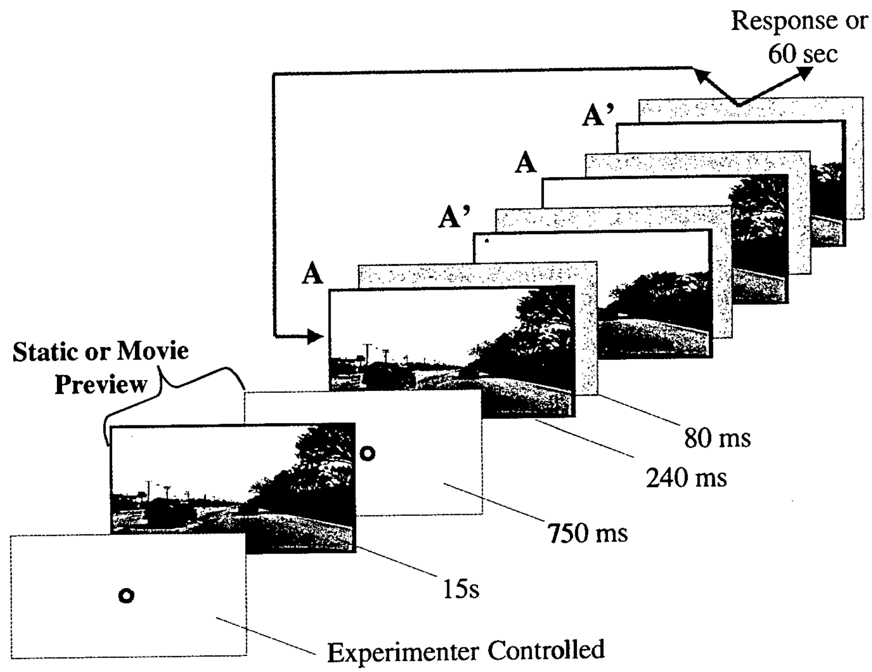

Figure 11. Perceptual change detection task for Experiment 2.

A bull's eye was displayed in the center of a gray screen, which participants were instructed to fixate. The experimenter manually initiated the trial after ensuring the subject's gaze on the center fixation point corresponded to an appropriate value on the eye data output. The static or movie preview condition (if applicable) was then presented for 15 seconds. Static/movie participants were allowed to freely scan the 15-second preview sequence, but upon the presentation of the second bull's eye (750ms), they had to briefly return their gaze to center. The flicker sequence automatically began when the second fixation point disappeared (or the first bull's eye disappeared for the flicker-only participants). Once the flicker sequence began, subjects were allowed to search freely for the image change. Upon detecting the change, subjects depressed the button on a handheld wand, and then verbally described the change (which was manually recorded by the experimenter). Subjects had up to 60 seconds to detect a change, although they were instructed to respond as quickly and as accurately as possible. Response time was measured from the first presentation of the scene, not including preview (if applicable).

Participants were told of the types of changes possible (i.e., object's color, size or presence) prior to beginning the experiment and were given practice trials to become familiarized with the task. They were not provided with feedback on their performance. Images and image changes (i.e., meaningfulness and

salience) were presented in a random order for each subject. The dependent variables were the response time (RT) needed to detect the change and the accuracy of the detection, as well as the fixation duration, location and scan pattern over the flickering scene.

Characteristics of the Objects, Changes and Pictures

As in Experiment 1, the meaningfulness and salience characteristics of both the object and its change were determined by independent judges. Nine younger (M=20.6 years) and 10 older adults (M=72.2 years) participated in a single pilot study examining the characteristics of the *change* (i.e., a modification of the properties of an object varying over time and occasionally over spatial location) and the characteristics of the *object* undergoing change (i.e., a recognizable item with consistent spatio-temporal properties). Each change and the object undergoing change were distinguished along two dimensions, meaningfulness and salience. Raters judged the changes or objects along one dimension (i.e., meaningfulness or salience) using a 6-point Likert scale before rating them on the other dimension. The order in which raters judged each characteristic (i.e., object meaningfulness, change meaningfulness, object salience, change salience) was counterbalanced across subjects. All other aspects of the pilot study were similar to Experiment 1.

Analyses of subjective ratings of the 80 driving scenes (excluding the scenes used in practice trials) were conducted to examine the range of variability in ratings of the pictures on the meaningfulness and salience scales and to determine the degree of similarity of meaningfulness and salience ratings for older and younger adults. Given the high correlation between meaningfulness and salience ratings for the objects and changes ($r = 0.74$, $p<.01$; 0.42, $p<.01$, respectively)[3], results will be reported in terms of the meaningfulness and salience ratings of the *change*. It should also be noted that a complete set of analyses based on the object ratings was conducted and those results are consistent with the results that follow (which are based on the ratings of the change).

The overall mean and standard deviation of the median ratings for salience were 2.50 and 1.17, respectively. The comparable ratings for meaningfulness were 1.88 and 1.96, respectively. Consistent with Experiment 1, raters judged the scene changes as varying to a greater extent in meaningfulness than in salience (although these means are slightly lower). No significant differences were found between young and old observers for mean ratings of salience ($t(17)= -1.17$; $p<.26$); however, older observers rated changes as more meaningful than younger observers ($t(17) = -2.35$, $p<.03$). This difference was not a concern, given the high degree of consistency for these groups on each of the rated dimensions (Cronbach's alpha = 0.95 and 0.96, for the rated meaningfulness and salience of the change, respectively).

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[3] Additionally, the ratings were compared with the experimenter's a priori assessments of change meaningfulness ($r=0.71$, $p<.001$) and change salience ($r=0.62$, $p<.001$) and given the high consistency between the ratings, it appeared that raters were complying with instructions.

The 80 driving scenes were then divided into four categories (i.e., low meaning/low salience, low meaning/high salience, high meaning/low salience, high meaning/high salience) for further analyses on the range of differences between low and high categories (see Table 4).

	LOW SALIENCE	**HIGH SALIENCE**
LOW MEANING	Meaning = 0.17 Salience = 1.33 (24 pictures)	Meaning = 0.12 Salience = 3.53 (17 pictures)
HIGH MEANING	Meaning = 3.12 Salience = 1.76 (17 pictures)	Meaning = 4.14 Salience = 3.55 (22 pictures)

Table 4. Mean ratings for change meaningfulness and salience.

As in Experiment 1, the range of differences between low and high categories were examined in terms of standard deviation (SD) units to determine the degree of equivalence for the meaningfulness and salience factors. That is, if the difference between high and low in SD units is approximately the same, then the meaningful changes in our pictures and the salience changes in our pictures would equated reasonably well. To convert these average ratings to SD units, the following formulas were applied:

$$\frac{Mn_{\text{High Meaning}} - Mn_{\text{Low Meaning}}}{SD_{\text{Meaning}}} \qquad \frac{Mn_{\text{High Salience}} - Mn_{\text{Low Salience}}}{SD_{\text{Salience}}}$$

Thus, given that the SDs for the meaningfulness and salience ratings were 1.96 and 1.17, respectively, then the difference between high and low meaningfulness for low salience pictures was (3.12 - 0.17)/1.96, or 1.51 SD units. For the remaining categories, the calculated values were 2.05, 1.88, 1.53 SD units for high - low meaningfulness for high salience pictures, and high - low salience for low and high meaningfulness pictures, respectively. Because the range of differences between low and high scores was approximately the same across categories (i.e., 1.51 – 2.05 SD units), it appears that the meaningfulness and salience change characteristics were reasonably equated in the pictures.

Design

Four factors were manipulated in the perceptual change detection task. The factors included age (2 levels: young, old), preview condition (3 levels: flicker, static, movie), change meaningfulness (2 levels: low, high) and salience (2 levels: low, high). Age and preview condition served as between subjects factors,

while meaningfulness and salience of the change were within subjects and randomized within trial blocks. The order of the scenes was randomized for all subjects.

Psychometric Assessment

In a separate, two hour session following the perceptual change detection task, participants were assessed in the following areas of cognitive and psychomotor function: attention, memory, perceptual speed and the ability to inhibit irrelevant information. The complete set of tasks and the order in which each was administered is provided in a table in Appendix D. Brief descriptions of the tasks are provided below.

Attention

In order to have the best opportunity to capture individual differences in attentional breadth, a subset of the FFOV task from Experiment 1 was used to assess differences in attentional breadth. In this task, each participant was measured on their ability to localize an oblique peripheral stimulus appearing at one of three eccentricities (10, 20, or 30 degrees from fixation) in the presence of 11 vertical distractors (refer to Figure 3). Targets appeared at random eccentricities on any given trial, and at least one distractor (but no more than two) appeared on each of the eight meridians. No foveal task was performed. All other aspects of the task were consistent with Experiment 1.

Participants completed two blocks of 144 trials each, with 48 practice trials to become familiarized with the task. Each individual's FFOV was defined as the eccentricity at which 50% accuracy was achieved on a best-fitting line of their performance on the FFOV subtask, as in Experiment 1 (see Figure 8). In order to eliminate the hypothesis that age differences at eccentric locations could be due to visual problems, two additional blocks were completed with oblique targets appearing without distractors. This baseline condition tested and showed that the older participants could indeed detect peripheral stimuli.

Working Memory

Tests were administered to assess multiple aspects of working memory, including executive function, visuo-spatial working memory and verbal working memory (see Table 5).

TESTS	COMPONENT AND DESCRIPTION
Backward digit span; Sequential and coordinative complexity arithmetic	Executive function: ability to manipulate information in short-term memory
Card rotations test; Maze tracing; Memory Tiles game, Visual reproduction immediate recall	Visuo-spatial memory: spatial orientation, scanning, spatial relations and the ability to associate object identity and spatial location information immediately after visual presentation
Verbal paired associates; WMS paragraph recall; Rey AVLT	Verbal memory: ability to immediately recall verbal material and associations between verbal material

Table 5. Psychometric measures of some aspects of memory.

Pilot studies were conducted on each of the subtests to ensure a range of performance scores within each age group, and at the same time, minimize scores at the extremes (i.e., reduce floor and ceiling effects). In order to achieve this, some departures from typical administration are noted in Appendix D. For example, stimuli used in the visual reproduction task were modified to ensure they were sufficiently difficult for young adults. Refer to Appendix D for details.

Perceptual Speed

Participants performed three paper-and-pencil tasks to assess perceptual speed (i.e., Box Completion, Digit Copying and Digit Symbol; Salthouse, 1992). These 3 tasks were selected because they provided a converging estimate of processing speed, and more importantly, they emphasized sensory/motor aspects of processing speed and minimized higher level aspects of processing (i.e., computationally demanding aspects) which might relate to working memory (Salthouse, 1992). For example, the Box Completion task required subjects to find the missing side of a series of boxes (squares) and fill in as many of the missing sides as possible within the allotted time. Appendix D provides detailed descriptions of these tasks.

Inhibition of Irrelevant Information

The ability to inhibit irrelevant information was also considered as a potential mediator in change detection performance and was gauged by performance on 3 tasks: the Stroop task, a Proactive Interference (PI) task, and the Rey Audio-Verbal Learning Test (AVLT). Together, these tasks provide converging estimates of the ability to inhibit irrelevant both verbal and visual stimuli. Refer to Appendix D for an overview of these tasks.

The Stroop task was selected because it demonstrates a robust interference effect when the participant is unable to ignore an irrelevant feature of the stimulus (e.g., the meaning of the word) while

attending to another (e.g., the color of the word). Typically, response times are slower when the color and word meaning are incongruent (e.g., the word "red" printed in blue ink) relative to when the color/word meaning relationship is neutral (e.g., a row of X's printed in blue ink).

The build-up of Proactive Interference (PI) in the PI task is measured by the decrease in performance over successive trials when the items share some attribute (Wickens et al., 1963; Wickens 1970). A few special considerations in the PI task administration are noted here. Because the primary reason for including this task was to measure PI buildup, release from PI was not examined. Also, vowels were excluded from the stimuli set to minimize the spontaneous use of natural language mediators to aid recall (Hulicka & Grossman, 1967). Finally, recall occurred immediately after presentation of the stimuli in order to avoid concerns about additional interference associated with particular types of filler tasks and to avoid concerns regarding the use of rehearsal during the delay interval (Tyrrell et al., 1981). Consequently, the lack of retention interval made the task slightly easier, but it was nonetheless sufficiently difficult for young adults, given the number of stimuli presented and results from a pilot study.

Finally, the Rey AVLT task was used to measure interference over the course of learning verbal material. In this task, performance on the first attempt to recall a word list is compared with performance on the first attempt to recall a different word list that occurred 5 trials later (i.e., following 5 repetitions of the first list). Thus, the ability to inhibit the first list would be important for recall of the second list and if inhibition were impaired, then trial 6 (i.e., 1st attempt on second list) would have lower recall performance than trial 1 (i.e., 1st attempt on first list).

Questionnaire

Subjective responses were collected on questionnaires assessing the participants' experience of immersion or presence in the scenes during change detection and their familiarity with the footage captured in the scenes (provided in Appendix G, adapted from Singer & Witmer, 1996). These estimates were included in order to assess the effectiveness of the scene meaningfulness manipulation in influencing viewers' engagement in the driving aspects of the scenes, independent of its effectiveness in influencing change detection performance.

Results

The data were examined to determine the influence of factors that mediated change detection performance. The first factors examined were intrinsic abilities, including attentional breadth, working memory, inhibition and perceptual speed abilities. It was hypothesized that in addition to attentional breadth, other intrinsic abilities would relate to change detection latency. Hierarchical regressions performed on the change detection response time data were expected to show that after removing the variance explained by attention, a significant portion of the remaining RT variance would be accounted for by individuals' performance on working memory, inhibition and perceptual speed tasks. Age was also

expected to relate to change detection performance, via a relationship with other measures, including attention and working memory. Thus, the age-related variance associated change detection RT was expected to diminish after accounting for individual differences on the psychometric tasks.

The role of extrinsic factors was examined via the role of change meaningfulness. First, it was hypothesized that a larger benefit for meaning should be observed for the young adults compared to older adults. Second, it was hypothesized that increasing the meaningfulness of scenes (via realistic motion and sound) would positively influence perceptual change detection for changes of high meaningfulness.

Finally, we examined how scene changes were reflected in eye movement behaviors. Specifically, fixations and fixation durations were anticipated to reflect differences in the visual processing of a changed location compared with the processing of that location when it was not undergoing change. Additionally, attentional breadth was expected to correspond with eye movement behaviors. For example, those with larger FFOVs should typically be able to make longer saccades and fewer dwells in the scene than those with smaller FFOVs.

The Role of Other Intrinsic Factors in Change Detection Performance

Intrinsic factors (i.e., attentional breadth, working memory, inhibition, and perceptual speed) were examined for their associations with change detection performance via regression procedures performed on the change detection RT data. Before these analyses could be conducted, age differences on the different psychometric tasks were assessed. Individual performance on each task was next combined into several composite measures representing each theoretical construct (i.e., working memory, inhibition, and perceptual speed; the single measure of attention was not combined) and the intercorrelations were examined. Then, to assess their relationship with change detection RT, the composite scores were entered into regression analyses. A hierarchical regression was first performed to examine the degree to which the other measures would account for performance on the change detection task beyond that which was accounted for by attentional breadth. Additionally, standard (block) and forward stepwise regressions were performed on the data to determine the priority ordering of the factors and the amount of common variance that could be accounted for. Finally, age-related variance in change detection RT was evaluated for the extent to which it would be mediated by other intrinsic factors, given that chronological age would not affect change detection performance as such, rather age is linked to performance via its relationship to other factors.

Assessment of Psychometric Tasks

Each of the subtests assessing attention, perceptual speed, working memory and inhibition abilities was first examined for age differences in performance. Since these results were not the focus of the study, results will be summarized (Appendix H). It is of interest to note that most measures showed reliable costs in performance associated with advanced age, with only 3 exceptions [i.e., the Easy Verbal Paired Associates

task, the Backward Digit Span and Rey-AVLT Interference measure (Trial 1 - Trial 6)]. A likely explanation for the finding on the Easy Verbal Paired Associates task was that it was too easy for both age groups. This conjecture is supported by a comparison of the maximum possible score on this measure (i.e., 12) with the means for each group (young = 11.2, old = 10.8). On the other hand, the lack of age-related decline in the Backward Digit Span was rather surprising in light of a significant amount of work (notably Salthouse, 1988; 1992) which suggests a strong link between this measure and age. Likewise, the finding on the Rey-AVLT Interference measure (Trial 1 – Trial 6) was surprising, but approached significance ($p<.08$) and supported the expected trend (i.e., that older adults would show greater interference on Trial 6 than younger adults).

It is suggested that these findings will have a minor impact on the analyses that follow. Although the age differences were non-significant, the general trends indicated a decline in performance with increasing age (and approached significance with 2 of the 3 measures). In addition, multiple measures were assessed for each psychological construct, including those constructs presumably tapped by the Easy Verbal Paired Associates task, the Backward Digit Span and the Rey-AVLT Interference measure (Trial 1 - Trial 6). Given that performance on these 3 tasks will be combined with other tasks to create a composite measure of the psychological construct (discussed next), the overall influence of any individual measure is reduced.

Relationship between Intrinsic Factors and Change Detection RT

To examine the hypothesis that perceptual change detection would be mediated by intrinsic factors in addition to attention, scores on the psychometric tasks were entered into a hierarchical regression as predictors of change detection response times, after attention was already entered. Prior to these analyses, the psychometric tasks (except attention) were combined into composite measures of each construct of interest and the intercorrelations were examined. Then, to assess the relationship with change detection RT, the composite scores were submitted to a hierarchical regression procedure. For purposes of the regression analyses, change detection RT referred to each individual's average response time across all pictures in which the change was correctly identified, excluding those times exceeding 3 standard deviations beyond the age-respective mean. Response time was considered a reasonable criterion measure of change detection performance since a speed and accuracy trade-off was not observed between age groups. Detailed analyses of the RT performance are provided in the section of the results entitled "Effect of Scene Meaning" (see below). Separate stepwise regressions were also performed on the data to determine the order of precedence for each construct and to determine the amount of common variance that could be explained. Finally, the variance in change detection RT accounted for by age was assessed and the extent to which the attentional, memory, inhibitory and speed abilities mediated this age-related variance was determined.

To facilitate comparison across measures with different means and standard deviations, standard z-scores were computed for each task (excluding the FFOV measure, since it represents a single construct). Z-scores were based on the overall group mean and standard deviation (i.e., across young and older adults).

As needed, the signs of the task z-scores were inverted so that performance across different tasks could be compared (e.g., so that high values on each composite measure corresponded to good performance). Composite scores were then derived from the average of these z-scores, representing a priori defined psychological constructs of perceptual speed, inhibition, and each of the identifiably different working memory constructs (see Appendix H).[4]

The use of composites can be justified as a means of reducing the data to variance-adjusted figures based on the work of Salthouse (1988, 1992). It is assumed that each task comprising the composite measure is equally important (i.e., equal weight). This simplification is justifiable as a starting point (Salthouse, 1992), but more importantly, the alignment of tests onto the composite measure was consistent with a factor analysis solution (i.e., the loading of factors).

Composite measures were entered into regression analyses to determine which ones would account for significant portions of the variance in change detection latency and in what order. Before going into the results of the regression, the intercorrelations will first be examined. A summary of the intercorrelations among the measures of interest is provided below (values greater than ±0.19 are significant at the 0.05 level). Note that high values on each composite measure correspond to good performance, while low values of change detection RT correspond to good performance (e.g., a higher perceptual *speed* relates to lower *response times*; see Appendix H).

	1	2	3	4	5	6	7	8
1. Age (cont)	1.00	0.83	-0.57	-0.34	-0.57	-0.79	-0.40	-0.44
2. Change Detection RT[a]		1.00	-0.67	-0.27	-0.51	-0.78	-0.44	-0.39
3. Attention[b]			1.00	0.15	0.33	0.61	0.30	0.25
4. Composite Inhibition[b]				1.00	0.21	0.34	0.09	0.12
5. Composite Perceptual Speed[b]					1.00	0.56	0.36	0.38
6. Composite Visuo-Spatial WM[b]						1.00	0.52	0.48
7. Composite Executive Function[b]							1.00	0.27
8. Composite Verbal WM[b]								1.00

Table 6. Intercorrelations among the measures of interest. Note that correlations greater than ±0.19 are significant at $p<.05$. [a]Low values correspond to better performance. [b]High values correspond to better performance.

[4] The visuo-spatial working memory composite was originally considered as two separate composites: visual working memory and spatial working memory. Due to the high intercorrelation (r=.75) of these factors, they were instead combined into the single visuo-spatial working memory composite.

Table 6 shows that several variables were strongly related, particularly to the age of the participants. In fact, age (as a continuous variable) was related to performance in all areas. Another composite that was highly related to other variables was visuo-spatial WM, which was associated with FFOV, perceptual speed, executive function and verbal WM.

It is important to note that despite the fact that some variables were highly correlated, the assumption of multicollinearity is met for the *predictor* variables. In other words, the correlations between FFOV, Composite Inhibition, Composite Perceptual Speed, Composite Visuo-Spatial WM, Composite Executive Function and Composite Verbal WM are sufficiently low (i.e., $r<0.70$; Tabachnick & Fidell, 1989) to suggest multicollinearity is not a problem. Previous indications that perceptual speed may subserve executive function and inhibition (e.g., Salthouse & Babcock, 1991; Lindfield & Wingfield, 1999) were not concerns in these data, as the correlations were moderate ($r=.36$ and .21, respectively). Although these relationships were significant, the high intercorrelations with age is not a problem for conducting regressions between measures of the theoretical constructs of interest and change detection RT. Age was not considered as a *predictor* of performance on change detection, rather its relationship with change detection RT is the result of its relationship with the other measures of theoretical constructs. This will be addressed in more detail below.[5]

Multiple regressions were performed on the change detection response times, using the factors in Table 6 as predictors, to examine the hypothesis that perceptual change detection is mediated by attention, inhibition, memory and perceptual speed abilities. A hierarchical regression was first performed on the data to examine the hypothesis that other intrinsic factors, in addition to attention, would predict change detection performance. Thus, attention was entered first into the regression, followed by all other factors (as a set). Results are provided in Table 7 below.

	Multiple R	Multiple R-square	R-square Change	F-to-enter	p-level
ATTENTION	0.671	0.450	0.450	122.02	.0000
ALL OTHER FACTORS	0.826	0.683	0.232	18.200	.0000

Table 7. Results of hierarchical regression specifying "attention" first, then all other factors.

The results presented in the Table 7 suggest that other factors can account for perceptual change detection performance beyond what attention can account for. In the first place, it is evident that attention

[5] Other assumptions critical to the regression procedure appear to have been met (i.e., that the relationship between each predictor and the criterion was linear, the redundancy between variables was minimal, distributions were normal), thus suggesting that the results of regression analyses would be interpretable.

accounts for a significant portion of the variance in change detection RT (i.e., over 45% of the variance is explained by attention alone, p<.001). After portioning out the variance associated with attention, the other factors (i.e., inhibition, perceptual speed and various aspects of the working memory) as a set, account for significant *additional* variance (r^2= .232, p<.001). Together, attention and the other factors account for over half of the variance in change detection RT (i.e., 68%), leaving approximately 32% of the variance unexplained.

Given that attention is one of several predictors in change detection performance, it would be interesting to look at this relationship further so that the independent contributions of these factors could be determined. One way to do this is via a standard (block) regression in which all variables are entered into the regression equation in a single step. The independent contributions to performance are typically represented by the B coefficient, but these values are not directly comparable given their dependence on the respective units of measurement (e.g., comparing degrees of FFOV with the units of perceptual speed). Alternatively, the converted "BETA" coefficients provide comparable measures across variables. The results of a standard (block) regression performed on the RT data, with all 6 factors entered as predictors, are provided in Table 8.

ALL SUBJECTS R= .826 R^2= .683 F(6,124)=44.542 p<.001 Std.Error of estimate: 2.201				
	BETA	Std Error of BETA	t(124)	p-level
ATTENTION	-0.315	0.064	-4.901	0.000
INHIBITION	0.025	0.055	0.456	0.649
PERCEPTUAL SPEED	-0.110	0.062	-1.781	0.077
EXECUTIVE FUNCTION	-0.038	0.060	-0.637	0.526
VERBAL WM	-0.024	0.059	-0.412	0.681
VISUO-SPATIAL WM	-0.488	0.086	-5.645	0.000

Table 8. Results of standard (block) regression.

It is evident from the results shown in Table 8 that the variance in change detection performance (68%) is predicted by a combination of attention, inhibition, perceptual speed and working memory. However, the hypothesized factors did not account for equivalent amounts of the variance and what's more, some of the proposed factors did not account for *significant* portions of the RT variance. Specifically, attention and visuo-spatial working memory each show a strong association with change detection performance (p's <.001), while the remaining factors (i.e., inhibition, perceptual speed, executive function and verbal working memory) failed to show a relationship with change detection performance, although perceptual speed approached significance (p<.08).

The results of the standard block analysis suggest that the group of factors explained a significant amount of the variance but some of the factors did not make independent contributions. It would be useful to examine if indeed a subset of the factors could explain a significant amount of the variance and the benefit to be gained by adding each subsequent variable to the regression equation. This can be assessed via forward stepwise regression analyses. In this approach, the independent variables are individually added to the model at each step of the regression until the "best" regression model is obtained. In other words, it starts with the "best" factor of the set, and determines the additional variance explained by the second best factor, and so on (i.e., as long as the predefined F-value is exceeded). Typically, the F-to-enter value is set at 1 and variables not meeting that criterion are considered trivial, but for the purpose of evaluating all the variables of interest in turn, the F-to-enter value was set at 0.0001. Results are presented in Table 9 below.

	Step +in	Multiple R	Multiple R-square	R-square Change	F-to-enter	p-level
VISUO-SPATIAL WM	1	0.783	0.612	0.612	203.806	0.000
ATTENTION	2	0.819	0.672	0.059	23.058	0.000
PERCEPTUAL SPEED	3	0.825	0.681	0.010	3.871	0.051
EXECUTIVE FUNCTION	4	0.826	0.682	0.001	0.354	0.553
PI BUILDUP	5	0.826	0.683	0.000	0.186	0.667
VERBAL WM	6	0.826	0.683	0.000	0.170	0.681

Table 9. Results of forward (stepwise) regression.

As Table 9 shows, 2-3 factors are important in predicting change detection performance. The top 3 predictors were (in order of precedence) visuo-spatial working memory, attention and perceptual speed. Together, they explained 68% of the RT variance, with visuo-spatial WM accounting for the lion's share (i.e., 61%). It is interesting to contrast these results with results discussed earlier. Recall that in the hierarchical regression (Table 7), attention was forced into the analysis first and accounted for 45% of the variance. On the other hand, the forward stepwise regression revealed that attention accounted for 6% of the variance, beyond that which was already accounted for by visuo-spatial WM, suggesting that the two factors share some of the explained variance. Further analyses revealed that the shared variance between attention and visuo-spatial WM accounted for 39% of the 67% of the variance explained by the 2 factors (leaving 22% of it attributable to visuo-spatial WM). This issue is treated more thoroughly below.

These results also suggest that perceptual speed may predict change detection performance, although it accounts for only 1% of the 68% of the variance already explained by the other 2 factors. The perceptual speed contribution is slightly different across the results from the block regression and the forward stepwise regression and is attributable to how the two regressions were performed. In the block regression, the contribution of a factor (e.g., perceptual speed) is considered in light of the contributions of

all the factors. In the forward stepwise regression, the contribution of a factor is considered in light of only the factors preceding it (e.g., visuo-spatial WM and attention).

It was somewhat surprising that the remaining factors were not associated with performance on change detection, and hence, a closer look at the findings is warranted. Looking back at the correlation analyses (Table 7), it appears that inhibition, executive function and verbal working memory do relate to performance on the change detection task. It is possible that these factors do in fact account for variance in change detection performance when considered singularly, but not in conjunction with some (or all) of the other measures. This would suggest that they share some degree of the variance. If it is the case that the factors in question (i.e., inhibition, executive function and verbal working memory) do not relate to change detection performance, then forcing them into separate hierarchical regressions as the initial variable should not achieve significance. However, if the factors share some of the variance, then forcing each factor into a unique regression should reveal a relationship with change detection RT. Thus, separate hierarchical regressions were performed, one regression for each of the remaining factors (i.e., inhibition, executive function and verbal working memory). Perceptual speed was also analyzed separately, given its moderate correlation with change detection RT and the small contribution found in the previous analyses. Each analysis forced a single variable into the regression equation in order to determine if a relationship with change detection RT existed. Results are provided below (Table 10).

	R	R-square	t(129)	p-level
INHIBITION (1^{st})	0.269	0.072	3.167	.002
PERCEPTUAL SPEED (1st)	0.515	0.265	-6.818	.000
EXECUTIVE FUNCTION (1st)	0.436	0.190	-5.504	.000
VERBAL WM (1^{st})	0.392	0.154	-4.846	.000

Table 10. Results of 4 separate hierarchical regressions forcing in one factor each.

As Table 10 shows, inhibition, perceptual speed, executive function and verbal working memory account for significant amounts of the variance in change detection RT (p's <.002), but only when considered as the first variable. In other words, they do not appear to account for performance beyond that which is already explained by attention and visuo-spatial WM. It is also useful to consider the magnitude of the contributions in Table 11. Although these measures can account for significant portions of the variance in change detection RT, up to one-quarter of the it when considered initially, they are of secondary

importance when compared with the contributions of attention ($r^2 = 0.45$, Table 7) and visuo-spatial WM ($r^2 = 0.61$, Table 9).

A final set of regression analyses were conducted to examine the extent to which any age-related variance in change detection RT would be mediated by individual differences in performance on the psychometric tasks. After determining the amount of age-related variance in change detection RT ($r^2=.687$, $p<.001$), the residual age-related variance was computed after controlling for potential mediators (i.e., attention visuo-spatial WM and perceptual speed). The degree of attenuation in age-related variance corresponds to the strength of the mediator influence. The result of these analyses is depicted as the percent of the total age-related variance affected by each of the examined mediators [i.e., the age-related variance ($r^2=.69$) was set to 100%; see Figure 12].

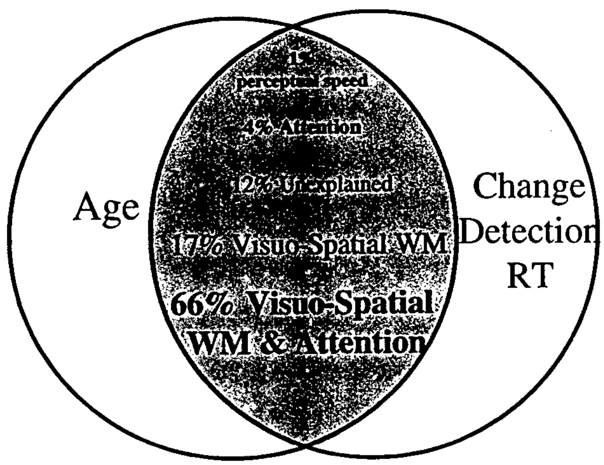

Figure 12. Percent of total age-related variance in change detection rt (age-related variance set to 100%) accounted for by attention, visuo-spatial working memory and perceptual speed.

As shown in Figure 12, the same factors that directly corresponded to change detection performance also mediated the relationship between age and change detection performance. Very little of the age-related variance was not explained by one of the hypothesized factors [i.e., given the age-related variance ($r^2=.69$) was set to 100%, then unexplained variance=12% of the total age-related variance or $r^2=.084$ of .69]. The rest of the age-related variance was attributed to visuo-spatial WM (17% of 100% or $r^2=.118$), attention (4% of 100% or $r^2=.024$), perceptual speed (1% of 100% or $r^2=.001$) or both attention and visuo-spatial WM (66% of 100% or $r^2=.298$). Inhibition, executive function and verbal WM did not correspond to the age-related variance ($p>.90$).[6]

[6] Two additional analyses evaluated the role of inhibition in change detection. Regression analyses were performed with a modified inhibition composite, which excluded performance on the PI Buildup task, due to the lack of an age difference on the task. This had minimal implication for the results reported. Another analysis compared false alarm rates in the first half of the experiment with the

Overall, these results seem to suggest that attention is one of several mediators in change detection performance and visuo-spatial working memory may be of particular importance in this relationship. The relationship found between attentional breadth and performance supports the idea that breadth of attention may be important for change detection (e.g., Rensink et al., 1997; Scholl, 2000) and that it may relate to the efficiency of scanning the scenes (consistent with Experiment 1). The additional finding for a link between visuo-spatial working memory and change detection performance is consistent with the hypothesis that attention is necessary but not sufficient for successful change detection (Levin & Simons, 1997). In addition, the findings are in agreement with the claim that memory for objects and their locations supports successful perceptual change detection and our representation of scenes (Irwin, 1996; Irwin & Gordon, 1998).

Effect of Scene Meaning

The purpose of the following analyses was to examine the role of extrinsic factors on change detection performance (i.e., the roles of change characteristics and scene context). Two hypotheses were examined in the data. The first hypothesis, based on the results of Experiment 1, was that change meaningfulness would enhance detection for older and younger adults and this benefit would be moderated by change salience and age. The second hypothesis examined, based on findings that one's engagement in scenes can be influenced by motion and sound, is that an increase in contextual relevance (implemented as the movie preview) would increase the observers' attention to meaningful aspects of the scenes and result in improved detection of highly meaningful changes, while detection of low meaning changes should be unaffected by the scene context. The meaningfulness effect due to increased scene context would be indicated by a two-way interaction between preview and meaning.

To investigate these hypotheses, separate 2X3X2X2 (Age X Preview X Meaning X Salience) mixed model ANOVAs were conducted on the change detection accuracy and latency (RT) data. Data for 131 subjects (66 young, 65 old) served as the basis for the analyses (note that ANOVA tables are provided in Appendix I). For the accuracy analyses, misses and false alarms constituted errors. For the RT analyses, only correct trials were assessed. Before carrying out this analysis, the data were initially examined to ensure that both age groups had sufficient correct trials to analyze across meaningfulness and salience categories.

Correct trials served as the basis for other analyses (e.g., response time analyses) and hence, the accuracy rates across condition and age were examined. The overall accuracy rates across condition and age are listed below in Table 11. Hits refer to those trials in which the viewer detected and correctly identified

latter half. Recall that Flicker et al. (1990) showed that older adults had more false alarms (FA) in the latter half of the experiment compared with the first, while younger adults showed no difference. In the present experiment, repeated measures ANOVAs were conducted on the false alarm rates for young and old adults. For those subjects who responded incorrectly (n=59), FA rates actually *decreased* from the first half to the second half of the experiment ($F(1, 57) = 5.55$, $p<.02$). Although older adults had a higher rate of false alarms overall ($F(1, 57) = 7.18$; $p<.01$), the ageXhalf interaction was not significant eliminating the hypothesis that compared with younger adults, the older adults might show a smaller drop in FA rates due to buildup of PI.

the change, misses refer to those trials in which the 60 second time limit expired and the subject failed to respond, and false alarms refers to those trials in which the viewer detected a change, but reported the nature of the change incorrectly.

	Hits	Misses	False Alarms
FLICKER			
Young	94.6%	5.1%	0.3%
Old	79.8%	16.8%	3.4%
STATIC			
Young	94.9%	4.7%	0.4%
Old	80.0%	17.7%	2.3%
MOVIE			
Young	95.1%	4.4%	0.5%
Old	81.3%	16.2%	2.5%

Table 11. Accuracy rates for younger and older adults as a function of preview condition

As Table 12 above shows, observers were successful in detecting change (greater than 79% of all trials were correctly detected and identified) and fairly reluctant to incorrectly guess the nature of a change (false alarm rates lower than 4% across conditions, $\beta > 3$ across both age groups and conditions). Surprisingly, younger adults were more conservative in detecting change than older adults, evidenced by the young adults' lower false alarm rates and higher beta values ($\beta = 8.4 - 18.1$ across preview condition) compared with older adults ($\beta = 3.6 - 7.1$ across preview condition). Furthermore, they were less likely to miss a change than the older adults and consequently, they had higher rates of correct detection (i.e., hits) than older adults.

The pictures responded to correctly were also inspected with regard to change characteristics (i.e., meaningfulness and salience) to ensure that the correct trials were reasonably distributed across all categories of meaningfulness and especially salience. The impact of error rates on the older adults' results was more of a concern and hence, only those figures are reported. The mean numbers of undetected pictures in each category were 1.4, 3.0, 4.1 and 5.3 for the high meaning/high salience, low meaning/high salience, high meaning/low salience and low meaning/low salience categories, respectively. These results, in conjunction with the number of pictures assigned to those categories (as presented in Table 4, p. 46), revealed that a reasonable number of trials could be evaluated in each meaningful and salience category. On average, 20.6, 14.0, 12.9, and 18.7 pictures remained for the analyses of the effects of the high meaning/high salience, low meaning/high salience, high meaning/low salience and low meaning/low salience, respectively. Thus, a reasonable number of pictures remained in each meaningfulness and salience category after taking errors into account.

Meaningfulness Effects due to Age & Salience

The hypothesis examined, based on the results of Experiment 1, was that change meaningfulness would enhance detection for older and younger adults and this benefit would be moderated by change salience and age. These effects are captured in the accuracy and response time data, depicted in Figure 13 below.

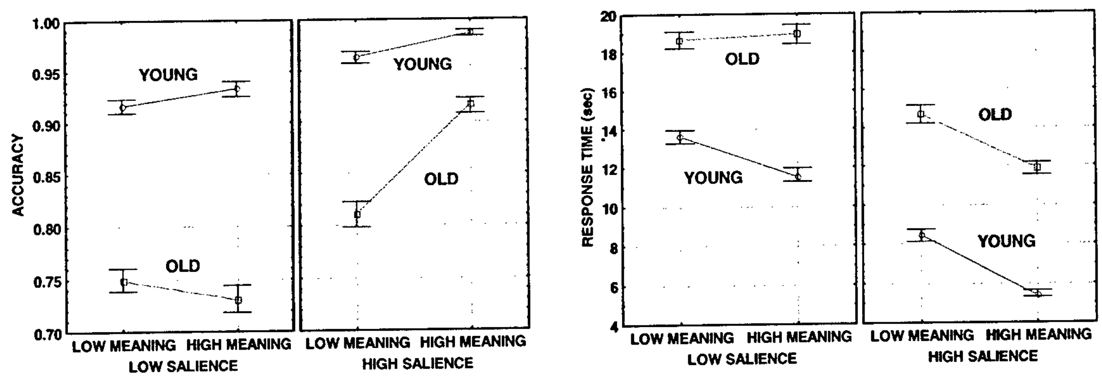

Figure 13. Age X meaning X salience interactions for accuracy (left) and response time (sec; right).

As shown in Figure 13, main effects were observed for age, meaning and salience, such that enhanced performance (in terms of higher accuracy and faster response times) was associated with younger age [accuracy: $F(1, 125) = 190.51$, $p<.001$; RT: $F(1, 125) = 191.03$, $p<.001$], high meaning [accuracy: $F(1, 125) = 31.03$, $p<.001$; RT: $F(1, 125) = 44.78$, $p<.001$] and highly salient changes [accuracy: $F(1, 125) = 194.35$, $p<.001$; RT: $F(1, 125) = 582.50$, $p<.001$]. Age had the strongest effect on response times and accuracy (young adults were 6.0 seconds faster, 15% more accurate than older adults), followed by salience (5.5s/9% difference between high and low salience changes), and then meaning (1.9s/3% difference between high and low meaning).

The main effects were mitigated by several significant two-way interactions (see Appendix I), which can best be understood in terms of the significant three-way interactions presented in Figure 13 above. The meaningfulness of the change did interact with age and salience, as in Experiment 1. Here, the interaction showed that increased meaning positively influenced change detection across both age groups and across high and low salience, except for older adults when salience was also low [accuracy: $F(1,125) = 27.15$, $p<.001$; RT: $F(1,125) = 6.16$, $p<.01$]. Scheffé post-hoc analyses indicated that increasing meaningfulness had no effect on performance for older adults when changes were of low salience (p's>.10). On the other hand, increasing meaningfulness aided the performance of older adults when changes were highly salient (p's<.05) and it generally aided the performance of younger adults for both low and high salience changes (RT: p's<.05; accuracy: $p_{high\ salience}<.05$, $p_{low\ salience}>.10$).

It is also interesting to consider at this point that subjective responses seemed to reflect these findings. Participants believed they emphasized looking for salient changes over meaningful ones. A within-subjects analysis on responses to subjects' attempts to look for changes that were meaningful compared with their efforts to look for changes that were salient (i.e., Questions 10 and 11, see Appendix G) revealed that participants believed they were attending to salience to a greater extent than they were attending to meaningfulness [$F(1,125)=4.79$, $p<.03$], but this did not differ across age [$F(1,125)=.177$, $p<.68$].

Recall that Experiment 1 showed that meaningfulness only influenced change detection when salience was low and there are several possibilities as to why this might be the case. In the Experiment 1, subjects in the high salience condition were performing faster overall than subjects in Expt 2 in the high salience condition. The faster responses in Expt 1 might have been close to or at ceiling performance; thus, a meaning effect wouldn't appear in the high salience condition. In Expt 2, where RTs were relatively slower and further from ceiling performance, meaning could show an effect. The slower responses in Experiment 2 might be attributed to the larger display size (i.e., 90X72 degrees in Expt 2 compared with 25X20 degrees of visual angle in Expt 1).

Another consideration is that the increase in the size of the display in Expt 2 could have enhanced the meaning or context of the scenes (across all preview conditions, not just movie preview), relative to Expt 1, because the increased field of view felt more "immersive". Also, note that ratings for meaningfulness and salience were judged by different raters who assessed these values with respect to the other pictures in the same experiment. Thus, what is judged as "high" (or "low") in one experiment may not be categorized as "high" (or "low") in the other, although "high" versus "low" within the same experiment appeared to be reasonably distinct on the basis of the pilot study (refer to p. 16).

Finally, Experiment 1 was partially replicated here. An apparent ceiling effect in Experiment 1 was eliminated in Experiment 2 under the high salience condition, such that meaning was found to enhance detection in the high salience condition for both older and younger adults. The results of Experiment 2 were consistent with Experiment 1 in that meaning enhanced detection of low salience changes only for young adults, but not for older adults. The findings in the accuracy data of Experiment 2 suggest that older adults are not sensitive to meaningful changes of low salience because they do not see them. Overall, older adults are more likely to miss detecting an inconspicuous change (i.e., low salience), regardless of its meaning to the scene context; however, the eye movement data will reveal that older adults are perhaps initially sensitive to meaning under low salience conditions, but the effect is attenuated over the duration of a trial.

Meaningfulness Effects due to Increased Scene Context

It was hypothesized that increasing the meaningfulness of scenes (via realistic motion and sound) would positively influence perceptual change detection for changes of high meaningfulness. This prospect was inspected via two-way interactions between preview condition and meaning (Preview X Meaning) in the accuracy and response time data, depicted in Figure 14 below. Additionally, responses from a post-experiment questionnaire were assessed to determine if indeed the movie manipulation was successful in creating a realistic environment, and if participants believed that the movie preview also influenced their performance.

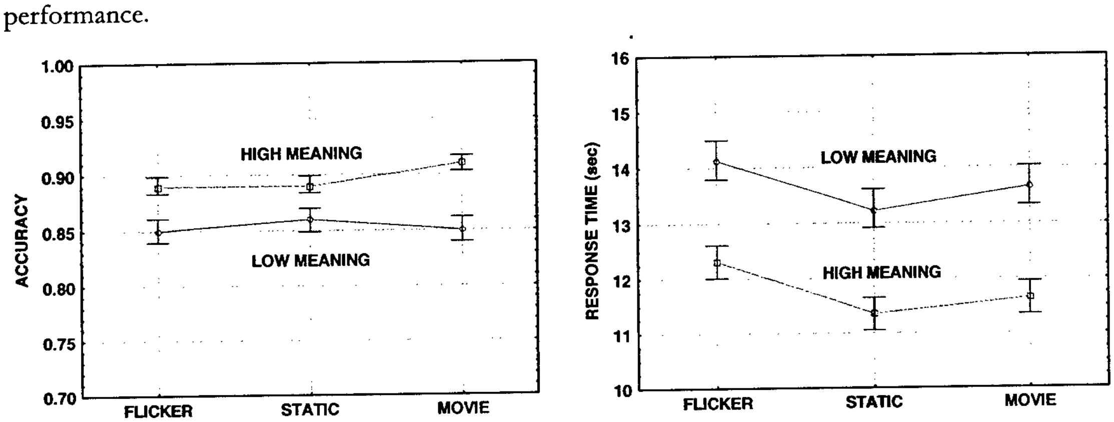

Figure 14. Meaning X preview interactions for accuracy (left) and response time (sec; right).

Note that in Figure 14, accuracy rates and response times failed to differ as a result of preview condition [preview effect: $F(2, 125) = .339, p<.71$; $F(1,125) = 0.34, p<.72$, respectively]. Moreover, increasing the meaningfulness of the scene did not appear to benefit the detection of highly meaningful changes, when meaningfulness was defined in terms of the picture change qualities [Preview X Meaning: accuracy: $F(2,125)=1.52, p<.22$; RT: $F(2,125)=.04, p<.96$].[7] The lack of a finding could not be attributed to differential effects of the movie context on the older adults because the three-way interactions were not significant [Age X Preview X Meaning, accuracy: $F(2,125)=2.32, p<.10$; RT: $F(2,125)=.830, p<.44$].

Other potential explanations are that the "realism" manipulation was not effective in making subjects feel more immersed, relative to other conditions, or that despite the feeling of immersion, it did not influence performance. The analyses on the subjective questionnaire attempted to examine these possibilities. Separate ANOVAs were conducted on each of the questions, using age and condition as between-subjects factors (note: given the large sample size, nonparametric procedures were not

[7] Separate pilot studies were conducted to assess meaningfulness of items in the scene in terms of static object qualities, the picture change qualities or the dynamic properties of the movie. Nonetheless, it did not appear that enhancing the scene context (i.e., movie preview) benefited the detection of highly meaningful changes, regardless of whether meaningfulness was defined in terms of the static object qualities, the picture change qualities or the dynamic properties of the movie (Preview X Meaning, accuracy: p's>.29, RT: p's >.88).

appropriate). Responses were available for 128 participants (63 young, 65 old). The full set of questions is provided in Appendix G, shown below are the subset that yielded significant results (Table 12).

QUESTION	FLICKER Mean (SD)	STATIC Mean (SD)	MOVIE Mean (SD)	
2) While looking for changes, I felt like I was... (1=in a lab, 7=in a car driving)	3.24 (1.56)	3.41 (1.60)	4.08 (1.47)	F(2,122)=3.59 p<.03
4) How real did the driving scenes seem to you (1=artificial, 7=indistinguishable from real world)	4.79 (1.53)	4.26 (1.73)	5.12 (1.09)	F(2,122)=3.56 p<.03
5) To what extent were there times when you felt that you were in a car and you almost forgot about the real world outside (1=never, 7=almost all the time)	2.34 (1.25)	2.57 (1.35)	3.47 (1.56)	F(2,122)=7.23 p<.001
9) How did scene preview influence how you searched for change (1=not at all, 7=completely)	n/a	5.06 (1.48)	4.34 (1.61)	F(1,122)=4.53 p<.04

QUESTION	YOUNG Mean (SD)	OLD Mean (SD)	
6) What was your overall enjoyment viewing these scenes (1=not at all enjoyable, 7=very enjoyable)	5.11 (1.42)	4.57 (1.51)	F(1,122)=4.32 p<.04
8) How high was your self-confidence in your ability to detect change (1=not at all confident, 7=completely confident)	5.13 (1.07)	4.19 (1.32)	F(1,122)=19.57 p<.001

Table 12. Post-task questionnaire.

It can first be seen in the table that four questions yielded significant differences with respect to preview condition. In the first place, it is evident by the responses that the "realism" manipulation (movie condition) was effective in creating a more realistic driving context. Scheffé post-hoc analyses confirmed that movie viewers were more likely to feel like they were in a car (compared with flicker-only viewers, p<.04), viewed the scenes as more realistic (compared with static preview, p<.03), and they felt like they were in a car (forgetting the outside world) to a greater extent than all other participants (p's<.02). Unfortunately, static preview participants reported that the scene preview influenced their looking for change more than did the movie participants (p<.04). This supports the claim that despite the feeling of immersion, movie preview did not influence performance enough to be different from the static preview condition, and thus, it could account for the lack of a significant Preview X Meaning interaction.

Two questions identified age differences. The younger adults were more likely to enjoy viewing the scenes and they had more confidence in their ability to detect changes than did the older adults. While it is possible that the enjoyment of the scenes may have been of some benefit to younger adults behavioral responses (such as RT), the difference in confidence ratings is not likely to account for a large portion of

the variance in the age differences reported. One might expect that the young's greater confidence would result in riskier responding (i.e., overconfidence), but it was noted earlier that they actually show a conservative response bias (i.e., lower false alarm rates, higher beta) compared with older adults.

Finally, four questions showed no differences with regard to age or preview condition (refer to Appendix G for full set of questions). Everyone was equally familiar with the scenery, and distracting events affected all participants to the same degree (p's>.35). No group reported a differential emphasis in looking for meaningfulness or salience change characteristics (as evidenced by the non-significant age differences on Questions 10 and 11, p's >.70), although the means for each age group were moderately high (young = 4.9, 5.3, old = 4.8, 5.3, respectively).

Consistent with the response time and accuracy results, no differences were observed in subjective reports of looking for meaningful changes across preview conditions ($F(2, 122)=1.43, p<.24$). Thus, it appears that the movie preview did not differentially benefit detection of meaningful changes, compared with other preview conditions. One potential explanation is that the movie preview context was not "meaningful enough" to produce the desired effect on change detection. While the movie condition was reported to be more realistic and meaningful, relative to the static condition, it may not have been meaningful enough to produce reliable trends in the overt response data. It is possible that the duration of the movie was not sufficiently long to produce robust effects or perhaps the second fixation mark was too disruptive and did not allow the momentum of the movies to continue into the flicker sequence, even for a short period. It is also possible that the measure of overt response to the change was not sensitive enough to detect the effect of scene meaningfulness. An implicit measure may yield stronger results. This possibility will be explored in the next section.

Eye Movement Measures of Change Detection

The third hypothesis examined in this study was that eye movement behavior would reflect the detection of change when the observer was explicitly aware of the change and even when the observer may not be aware of the change. This was based on previous findings that suggest that eye movements are an indirect means of indicating visual processing of a scene. Fixations and fixation durations were anticipated to reflect differences in the visual processing of a changed location compared with the processing of that location when it is not undergoing change for both changes that were correctly detected (explicit/aware) and missed (implicit/unaware). In addition, eye movement behaviors were expected to elucidate the relationship between change detection and attentional breadth (i.e., FFOV), such that measures of saccadic amplitude and the number of dwells within the scene would relate to the size of one's FFOV. Finally, the possibility that eye movements might be more sensitive to preview effects, especially with regard to meaningful changes, was examined and will be reported where applicable.

Of the 131 subjects included in the study, equipment malfunctions resulted in a partial loss of data for 3 subjects (1 young, 2 old), and a complete loss of eye data for 7 subjects (5 young, 2 old). It was also important to ensure that within a given trial, the eye tracker adequately monitored the eye position. If the eye tracker "lost" the eye for more than 5% of the duration of a trial, the trial was excluded from the analyses. This criterion eliminated 4.7% of all trials averaged across subjects. As a result, a total of 9306 trials were available for analyses. The subjects' point of fixation was used as the basis for most eye movement behavior measures. A fixation was generally defined as the mean X and Y eye position coordinates measured over a minimum period of 100ms during which the eye does not move outside a delimited area (usually ±0.5 degrees). Dwells (also referred to as gazes) were distinguished from fixations in that they usually referred to consecutive fixations occurring in a given region (i.e., area of interest or AOI).

Results of the observers' eye movement behaviors first focus on performance where no change occurs, in order to establish a baseline for comparison with performance where change does occur. This is followed by an examination of explicit change detection in which performance during change (i.e., flicker) both prior to and during fixation on the change location was compared with performance during baseline. Additionally, attentional breadth was compared to saccade amplitudes and the number of dwells in a scene when change was explicitly reported. The last section investigates implicit change detection on trials in which a change occurred, but was not explicitly reported by the observer (i.e., miss trials).

Eye Movement Behavior During Baseline

Baselines for performance were necessary in order to establish that any age differences in the changing condition could not be accounted for by differences in the way that the young and old viewed the scene itself (i.e., in the absence of a change). Furthermore, the baseline analyses were used to establish the subjects' interest in the object selected for change (as measured by eye behavior) in the absence of any change. Baselines were determined from eye data collected during the 15-second static preview of the first (unmodified) image in the flicker sequence (n=19 young, 21 old observers). The behaviors observed during baseline were compared with behaviors during change (i.e., flicker) across all three preview conditions.

One way to compare young and old subjects' viewing of the unchanging (baseline) scenes is to examine the general dispersion of scanning. To this end, the ImmersaDesk display was divided into 9 regions, each subtending 30x24 degrees of visual angle. The percent of fixations in each region was tabulated as a function of the total number of fixations in the overall scene, with the top left box representing the top left corner of the display; the bottom right box refers to the bottom right corner of the display (see Table 13 below). Results of the analysis of variance using age (young, old) as a between-subjects factor suggested no differences in the patterns of viewing the regions of the display between younger and older adults.

Young **Old**	5.1% 4.1% F(1,38)=3.40, p=.07	8.6% 8.0% F(1,38)=0.77, p=.38	5.0% 4.9% F(1,38)=0.21, p=.88
Young **Old**	16.0% 14.3% F(1,38)=3.61, p=.06	32.4% 34.3% F(1,38)=0.75, p=.39	14.9% 14.1% F(1,38)=1.37, p=.25
Young **Old**	4.4% 4.7% F(1,38)=1.26, p=.27	9.6% 10.7% F(1,38)=3.14, p=.08	4.0% 4.8% F(1,38)=3.26, p=.08

Table 13. Percent of fixations in each region of the static preview display (e.g., top left of display, top center, top right...bottom right).

To examine this issue further, analyses were conducted on the old and young adults in terms of fixations and durations in each of three, mutually exclusive, areas of interest (AOIs) on the static scene preview. The first AOI (AOI 1) corresponded to the foveation of the object to be changed and was defined as the best fit around the object using 4 lines, plus approximately one degree of visual angle to account for error in the eye/head tracker. A second, parafoveal, AOI (AOI 2) referred to a border that was 6 degrees of visual angle beyond AOI 1, but did not include AOI 1. Finally, AOI 3 corresponded to any area of the scene not accounted for by AOI 1 or AOI 2. It should be noted that a slight bias in the eye tracker output was accounted for in the positioning of AOIs in the right half of the display by incrementally adjusting AOIs 1 and 2 inward (i.e., a left horizontal shift) as a function of the degree of bias.

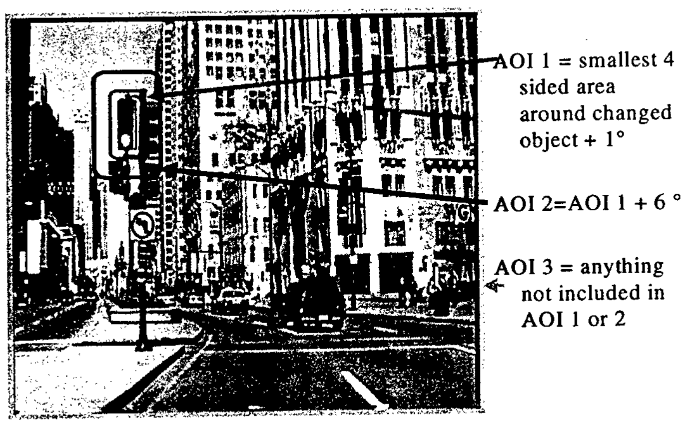

Figure 15. Definition of areas of interest (AOI).

For the most part, the 19 young and 21 old observers did not differ appreciably while viewing the unchanging scene (refer to Appendix J for a summary of these analyses). They appeared to visit most areas of the scene with the same frequency and spend approximately the same amount of time there, which is supported by the following measures: total number of fixations in AOI 1, percent fixations in each area,

average duration in each area, total duration and percent duration in AOIs 1 and 3 (p's >.08). Only a few significant differences ($p<.05$) emerged during the 15-second preview, the older adults appeared to visit AOIs 2 and 3 more frequently (Total Fixations AOI 2/3, young: 2.98/39.63; old 3.28/41.75, respectively) and to spend more time in AOI 2 (Total/Percent Duration AOI 2, young: 0.69s/6.49%; old 0.76s/6.93%, respectively). While the two age groups exhibited slight differences in their viewing of the parafoveal and peripheral areas (AOI 2 and 3), the magnitude of these differences is not a cause for concern. Most importantly, the area to-be-changed (AOI 1) was similar for young and old across the other measures and could justifiably be used as a baseline for subsequent analyses.

Measure of Explicit Change Detection

Given that old and young generally viewed unchanging areas of a scene in a similar manner, age differences in viewing the changing scene were then compared. Some of the main interests were in the amount of time and the number of fixations in the scene prior to landing on the change, providing an index of scene processing, or perhaps strategies, prior to detecting the change. Potentially, these measures could elucidate links between change meaningfulness and salience, age or scene preview. Saccadic amplitudes and overall dwells in the scene were also of interest, based on the hypothesis that size of the FFOV relates to the distance one needs to "travel" to scan the next portion of the unscanned scene and may consequently relate to the number of dwells in the scene and to detection times. Finally, patterns of looking at the change region were compared across baseline and explicit report of change detection. Differences in frequency and duration of fixations were expected.

Prior to detecting the change, observers scanned the scenes while the elapsed time, the elapsed number of fixations and their amplitudes were recorded. Mixed model ANOVAs [age (young, old); preview (flicker, static, movie); meaning (high, low); salience (high, low)] were conducted on these measures. A summary of pertinent results are provided in Table 14. The average saccadic distance within AOI 3 reflects only saccades that started and ended in that region. Since the region of the change (AOI 1) could not be analyzed in the same way due to its much smaller size, the distance of the first saccade to that region was calculated.

AGE	MEANING	SALIENCE	Elapsed Fixations To AOI 1	Elapsed Time To AOI 1 (sec)	Elapsed Distance To AOI 1 (deg)	Avg Saccade Distance In AOI 3 (deg)
Young	Low	Low	19.99 (5.55)	7.49 (1.95)	16.34 (2.58)	10.03 (1.15)
Young	Low	High	8.88 (2.45)	3.32 (0.82)	18.32 (2.96)	9.50 (1.22)
Young	High	Low	9.87 (3.44)	3.71 (1.21)	17.78 (3.28)	9.58 (1.44)
Young	High	High	7.42 (2.36)	2.78 (0.93)	15.81 (3.43)	9.38 (1.86)
Old	Low	Low	24.02 (7.03)	9.12 (2.48)	14.46 (2.99)	8.59 (2.33)
Old	Low	High	14.61 (4.63)	5.51 (1.73)	15.73 (3.70)	8.07 (1.65)
Old	High	Low	15.14 (5.31)	5.57 (1.81)	15.33 (2.85)	7.80 (1.47)
Old	High	High	13.47 (5.68)	5.08 (2.09)	13.07 (2.83)	7.95 (1.74)
		Age	.001	.001	.001	.001
		Meaning	.001	.001	.003	.001
		Salience	.001	.001	.345	.001

Table 14. Means (and standard deviations) of age and preview effects prior to landing on change.

Age differences were observed on all of the measures reported in Table 14, indicating slower performance, more fixations and saccades of shorter distances. It was first noted that older adults fixated more frequently (17.5 fixations) before landing on the change than did young adults [compared with 12.4 fixations for the young; $F(1,117)=51.12$, $p<.001$]. Additionally, older adults took a longer amount of time (6.1 sec) before landing on change compared with their younger counterparts [4.6 sec; $F(1,117)=62.79$, $p<.001$], suggesting that older adults were taking longer to process the scene. The distance traveled within AOI 3 was generally shorter for older (8.2°) than younger adults [9.7°; $F(1,117)=37.64$, $p<.001$], and the elapsed distance to the changed area was significantly shorter for older observers (14.5°), compared with the young (17.2°; $F(1,117)=51.12$; $p<.001$). In other words, older observers had to be closer to the change in order to land there.

Older adults' shorter saccades may be related to their decreased breadth of attention, which was examined in Table 16 below. It was hypothesized that the size of the FFOV would relate to the distance to the next unscanned area.

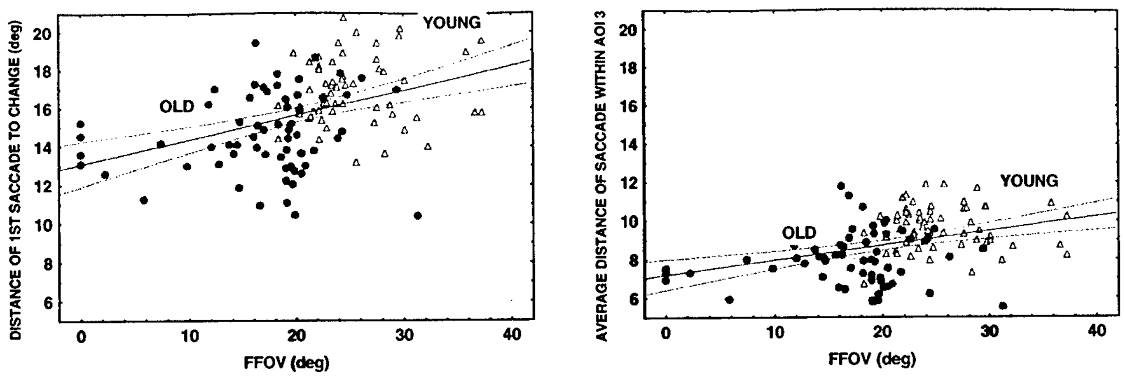

Figure 16. Relationship between attentional breadth (FFOV) and the distance of the first saccade into the change area (AOI 1; left) and the average distance of saccades within AOI 3 (right).

Figure 16 depicts the relationships between saccadic distances compared to attentional breadth (FFOV) within each age group across all preview conditions. The left figure shows the attention-saccade relationship in terms of the amplitude of the first saccade landing on the change (i.e., elapsed distance to AOI 1); the right figure depicts the attention-saccade relationship in terms of the average saccade distance in AOI 3. The correlations on the combined data were significant: r's=0.41, 0.33; p's<.001, for saccades to AOI 1 and within AOI 3, respectively. Within each age group, the correlations were not significant for either measure of saccadic amplitude (p's>.14). It may be that these relationships were not observed given the restricted range of both measures, especially in the saccadic amplitudes.

Before returning to Table 16, it is useful at this point to consider an additional eye movement based measure of the relationship between attentional breadth and change detection performance. It was assumed in both Experiment 1 and 2 that a broader attentional breadth related to faster change detection performance by decreasing the number of dwells (i.e., a group of sequential fixations in close proximity) needed to scan the scene for change. This assumption may be examined in the current data set (see Figure 17 below). Additionally, given the earlier finding that visuo-spatial working memory was a stronger predictor of change detection latency than attentional breadth, it was also examined whether visuo-spatial working memory had a stronger relationship with the number of dwells in the scene. In other words, a better memory of the scene would enable the viewer to have fewer dwells in the scene. These analyses are depicted in Figure 17 below.

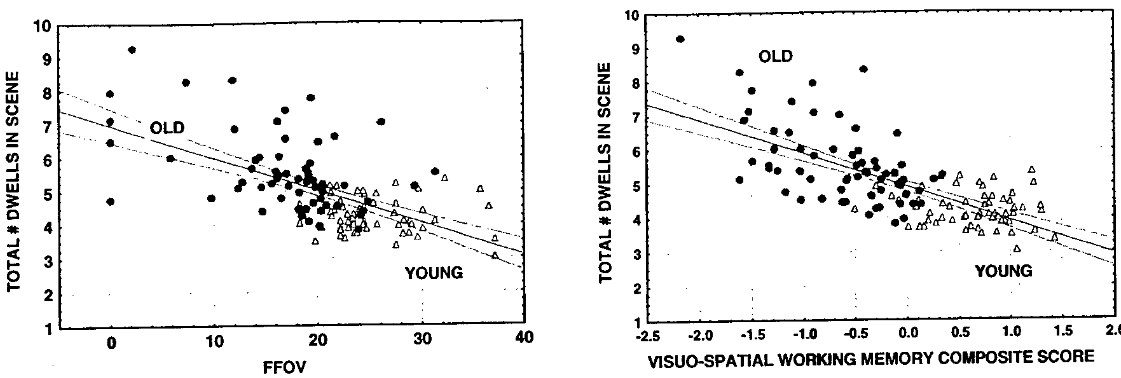

Figure 17. Relationship between the total number of dwells in scene and attentional breadth (FFOV; left) and. the total number of dwells in scene and visuo-spatial working memory composite score (right).

Figure 17 (left) depicts a strong, negative relationship between attentional breadth (FFOV) and the total number of dwells in the scene ($r=-.61$, $p<.001$, $n=121$); however, a stronger relationship was observed between visuo-spatial working memory and the number of dwells in the scene ($r=-.71$, $p<.001$, $n=121$). In considering each age group separately, the relationship was significant for old adults ($r=-.48$, $p<.001$), but not for young adults ($r=-.19$, $p<.16$). While it was supported that fewer dwells in the scene are required, on average, to detect the change when one has a broader attentional breadth, it appears that memory is more important in reducing the number of dwells or samples of the scene. This is consistent with the finding (discussed earlier) that visuo-spatial working memory was a stronger predictor of change detection latency than attentional breadth. Within each age group, a relationship was found between visuo-spatial working memory and dwells in the scene only for older adults ($r=-.58$, $p<.001$; young: $r=-.17$, $p<.19$). It should be noted that memory wouldn't necessarily allow the observer to make longer saccades in the scene, which would be better characterized by attentional breadth. Indeed, the relationship between visuo-spatial working memory and saccadic amplitude was similar, but weaker than the relationship observed between FFOV and saccadic amplitude (r's = .32, .41, p's<.001, for average saccade distance in AOI 3 and the amplitude of the first saccade landing on the change, respectively).

Returning to Table 16, main effects were observed for change meaningfulness and salience across most eye movement measures. Higher change meaningfulness and higher change salience related to less time [$F(1,117)=252.73$, $p<.001$; $F(1,117)=240.64$, $p<.001$, respectively] and fewer fixations [$F(1,117)=233.28$, $p<.001$; $F(1,117)=227.21$, $p<.001$, respectively] in the scene before landing on the change area. Significant two-way interactions were observed between meaning and salience for both the elapsed time until first landing in the change area [$F(1,117)=153.23$; $p<.001$] and the elapsed number of fixations in the scene until first landing in the change area [$F(1,117)=154.72$; $p<.001$]. It is of interest to note that the 3-way interaction between age, meaning and salience was not observed (elapsed time, elapsed fixations: p's>.50; see Figure 18).

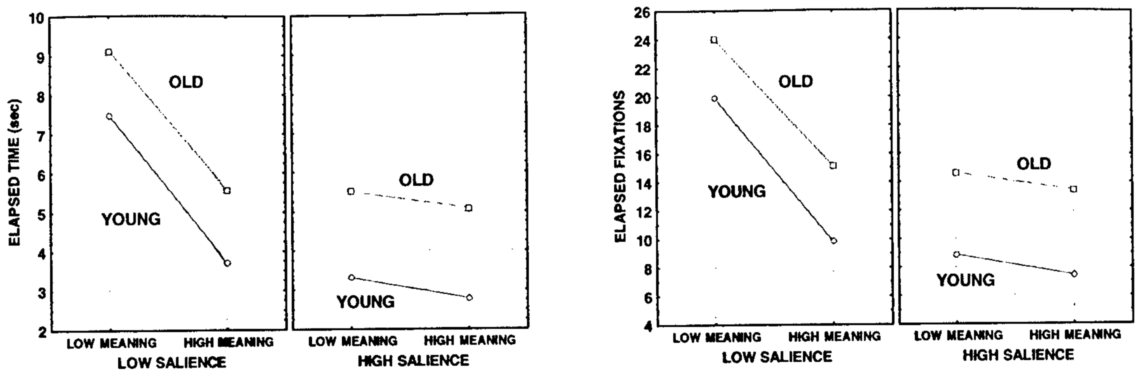

Figure 18. Age X meaning X salience interaction for elapsed time (sec; left) and elapsed number of fixations (right) in scene prior to landing on the change area (AOI 1).

Figure 18 depicts the effects of meaning, salience and age in terms of the elapsed time and elapsed number of fixations in the scene prior to landing on the change region. Younger adults generally landed on the change within fewer fixations than older adults, changes of high salience were landed on more quickly than changes of low salience and finally, changes of high meaning were landed on more quickly than changes of low meaning. What is especially interesting is that the ageXmeaningXsalience interaction was not significant (p's>.50). In the response time and accuracy data discussed previously, results indicated that older adults were not sensitive to meaning when the change was also of low salience. It now seems likely that the measure of overt response to the change was not sensitive enough to detect the effect of scene meaningfulness. In the figure above, older adults are sensitive to meaningfulness when the change is of low salience. In fact, they appear to be as sensitive as younger adults. Thus, it appears that older adults fixate meaningful change, but explicit response to the change is significantly delayed (refer back to Figure 13).

Significant main effects for preview condition were not observed in these data, however several measures were marginally significant and preview condition did interact with age on the average saccadic amplitude within AOI 3. The interaction suggested the age differences between preview condition [Age X Preview: $F(2,117) = 3.82$; $p<.02$] were smallest for the flicker condition and largest for the movie condition. Given the lack of corroborating evidence in other measures, this interaction is difficult to interpret. The marginal effect of preview condition ($p = .06$) implied that observers in the static condition landed on the changed area with fewer fixations on the scene compared with movie and flicker preview conditions (note a similar trend was shown in the RT data, Figure 14, p. 62). The effect, albeit marginal, would be consistent with a more efficient scanning as a result of a better representation of the scene (given a static preview), but further research will have to bear this hypothesis out.

We will now examine the effects of introducing change to the scene and compare each age group with the baseline (collapsing across preview condition). Recall that these analyses are based on trials where

change was detected and identified. The locations of the final fixations of a correct trial (i.e., the fixation at response) as a function of age and AOI are listed in Table 15.

	YOUNG	OLD
AOI 1	83.8%	82.3%
AOI 2	12.8%	12.0%
AOI 3	3.4%	5.7%

Table 15. Percentage of final fixations for correct trials in each area of interest (AOI) as a function of age.

As Table 15 suggests, the majority of trials ended with the observers fixating the change region (>82% of the time for both age groups). A smaller percentage of trials ended with the change located parafoveally and fewer still were the trials ending with the change located peripherally. Although these figures may also represent occasions when observers ended a trial late (i.e., after moving their eyes), an examination of the fixation just prior to the last one yields similar trends. Furthermore, these findings are consistent with Hollingworth and Henderson (1998), who found that fixation on the object undergoing change was important for successful change detection. Given that the vast majority of changes were detected foveally at response, henceforth, AOI 1 was considered as the primary location of change detection.

It was of interest to compare fixations in this region with other regions in the scene. Because response times varied, the number of fixations was calculated as a percentage of overall fixations in each AOI and is depicted in Figure 19 below. Recall that baseline viewing was established during the 15-second preview of the same scene in the static condition.

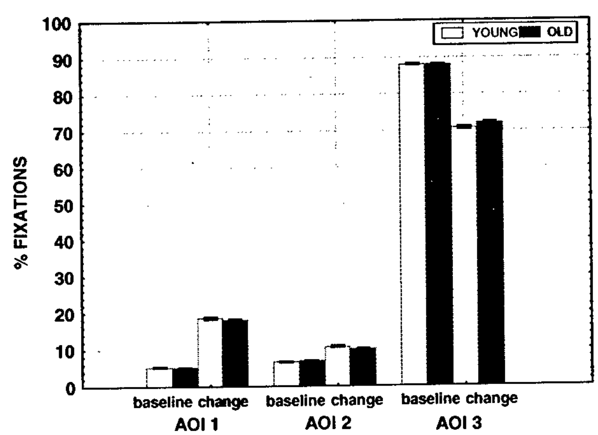

Figure 19. Percent fixations in each area of interest (AOI) for younger and older adults.

Figure 19 shows that for both age groups, a higher percentage of fixations landed on the change area when change occurred than when it did not. That is, a higher percentage of the total fixations landed in the changed area of the scene (i.e., AOI 1 and AOI 2) when it is actually undergoing change as compared to the baseline, when the area was not changed. The percentage of the total time spent in each region during change also closely matches these results (collapsed across age: 23.3%, 9.8%, 66.9%, in AOIs 1, 2 and 3, respectively).

Ongoing processing of the scene and change was also observed in the average duration of a fixation in each region. Consistent with the above findings, the average amount of time spent on the changed area was greater when it was changing than when it was not, especially for the older adults (see Figure 20 below). The average amount of time fixated in non-changing areas of the scene do not show as much time cost as the changing areas of the scene.

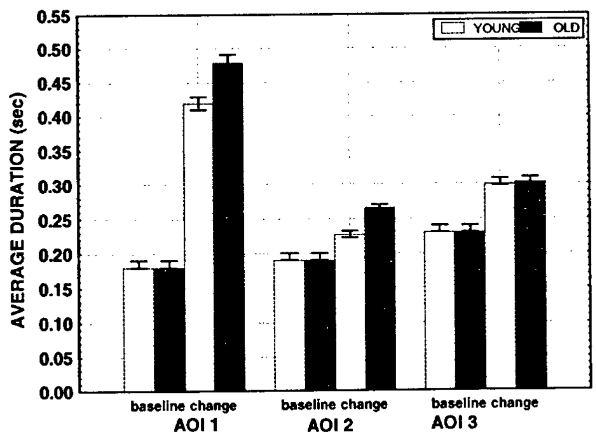

Figure 20. Average duration of fixations landing in each AOI.

Processing of the scene without interruption and without change (i.e., baseline) is similar across all regions of the display (e.g., average fixation duration 180-230ms). The average processing time in the unchanging area of the scene (AOI 3) for both young and old was approximately 300ms. With the addition of change (foveally, AOI 1; parafoveally, AOI 2), processing is affected even more and age differences emerge [$F(1,117) = 14.37$, $p<.001$]. Compared with fixation durations at AOI 3 during change fixation durations at AOI 1 are an additional 100ms longer for the young adults and 180ms longer for the older adults, suggesting that older adults had more difficulty in processing the change. This is unlikely to be the result of a more conservative bias on the part of the elderly, in light of their higher false alarm rates compared with younger adults (see Table 12).

Indirect Measure of Change Detection

The efficiency of observers' viewing was also explored implicitly, by examining performance when change was not detected. It was hypothesized that implicit change detection would be characterized by

increased viewing when change was not yet detected or missed completely, as compared to baseline viewing performance (i.e., the static 15-second preview). Increased viewing was measured by duration (i.e., average fixation duration) and frequency (i.e., percent of overall fixations, number of refixations/entries) and was first examined on trials in which change was not explicitly detected (i.e., misses). Trials in which change was only explicitly detected after several refixations of the change area (i.e., AOI 1) were also examined for increased viewing behaviors.

Increased viewing time was examined as a potential indicator of implicit change detection. If the change were detected without the observer's awareness, then the average duration of fixations on the change area (AOI 1) should be greater than baseline viewing. The data are presented in Figure 21 below.

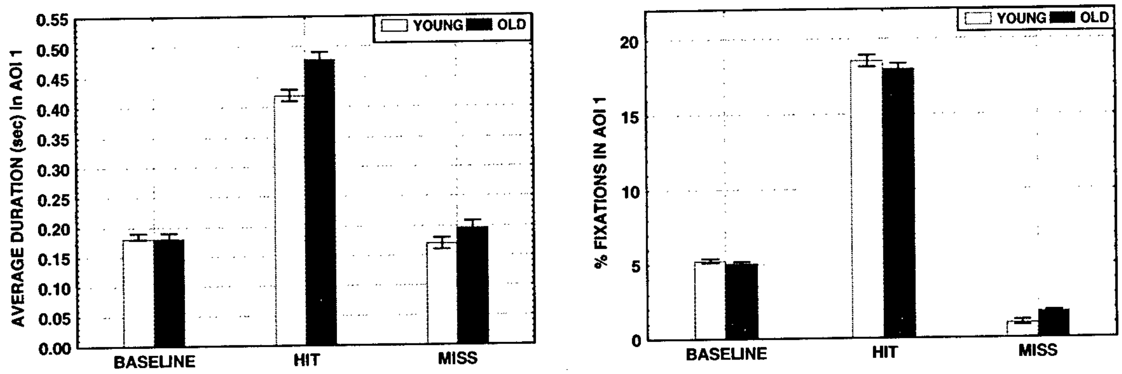

Figure 21. Average fixation duration (sec; left) and overall percent of fixations landing in AOI 1 (right) for hits and misses compared with baseline viewing.

As shown in Figure 21, the duration and frequency of viewing do not seem to suggest that observers implicitly detect change. Average fixation durations were equivalent for trials in which change was present but not detected compared to trials in which change was not present [baseline; $F(1,37)=1.85$, $p>.18$][8]. Younger and older adults did not differ in their average viewing duration on miss trials [$F(1,37)=.04$, $p>.83$]. This behavior is much different from the increased viewing observed when the change was explicitly detected (i.e., hits; see previous discussion). Additionally, the overall percent of fixations landing on the change region (AOI 1) on miss trials was not greater than the frequency of viewing the baseline. In fact, it was much lower than the baseline [($F(1,37)=404.70$, $p<.001$], even more so for young adults [i.e., age X viewing during baseline or miss trials interaction; $F(1,37) = 6.08$, $p<.02$]. It could be argued that miss trials were much longer than baseline or hit trials and artificially decreasing the overall percentage; however, the raw number of fixations in the change area shows that misses were fixated as frequently as baseline viewing, but not more [$F(1,37)=.95$, $p>.34$]. Furthermore, one would expect that if implicit detection occurred, then despite the longer trials, observers would have more opportunities to view

[8] Within subject comparisons were made with baseline viewing for static preview observers since their performance on these measures did not differ significantly ($p>.30$) from flicker and movie condition observers.

the change and would therefore increase the frequency of fixating the change, rather than decrease it. In general, the probability of fixating the change area should increase as more fixations elapse, and indeed this was found in the data (see the figure below).

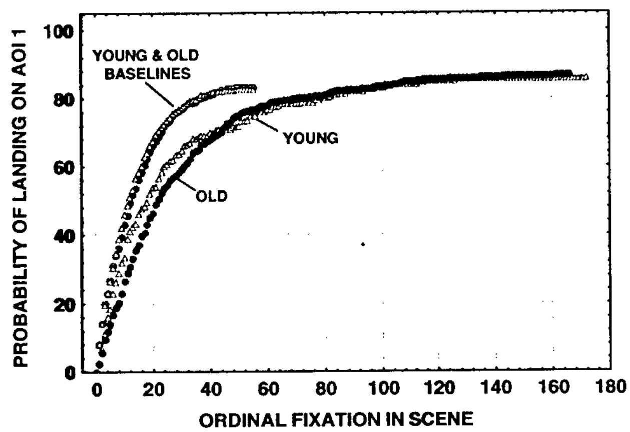

Figure 22. Cumulative probability of landing on change (AOI 1) for miss trials only as a function of ordinal fixation in scene.

Each successive fixation in the scene (i.e., first fixation, second fixation, and so on) has a higher probability of landing on the change area than the previous one, to a point. This is predicted if subjects have some memory of where they previously scanned and are less likely to revisit (in contrast to "amnesic" search; Horowitz & Wolfe, 1998). The probability of landing on the change is not greater for miss trials than baseline trials, although it may be that the young subjects are closer to baseline on earlier fixations than the older subjects. This is supported by the following graph depicting the number of fixations elapsing before the eyes first land on the change area (AOI 1).

Another means of expressing the frequency of visitations in the change area is the number of entries (or visits) to the area undergoing change. If change is detected implicitly, then observers might refixate the area undergoing change more frequently than when it is not undergoing change. In Figure 23, the number of entries to the foveal change areas (AOI 1) is presented for younger and older adults according to the accuracy of detecting change in the trial.

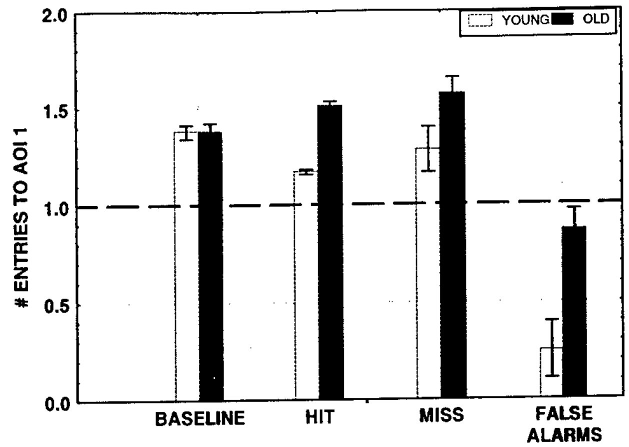

Figure 23. Total number of entries to foveal change region (AOI 1).

Figure 23 first establishes that visitations to the same area, when no change occurred (i.e., during baseline), no age differences emerged. However, when change occurred and it was correctly identified, old and young differed in the number of total visits to the change [1.2 times for young; 1.5 for old; $F(1,117) = 52.63$; $p<.001$]. It is interesting to note that both age groups, on average, visit the changed area more than once. Although an interaction between age and condition (miss vs baseline) approached significance ($p>.07$), the number of entries to AOI 1 were equivalent to the 15-second baseline for both young and old adults (p's>.19).

One might expect that for trials where change was missed the region undergoing change was never visited; however this does not seem to be the case. Figure 23 suggests that typically the region undergoing change was visited at least once during the 60 seconds of the trial, but it was not sufficient to ensure the change was detected. The number of entries to the change area on miss trials did not differ from baseline viewing [$F(1,37)=.01$; $p>.94$]. This was true for both young and old adults [young: $F(1,37)=1.75$, $p<.19$; old: $F(1,37)=1.73$, $p<.20$]. Finally, false alarm data (though sparse) seems to be the result of the observers responding prematurely (i.e., failing to visit the change area before response), rather than visiting the change area and naming it incorrectly (number of visitations <1.0). Taken together, it appears that visiting the changed area at least once occurred across all conditions (excluding false alarms) and was necessary to correctly identify change, although it does not guarantee explicit detection. Finally, it was found that observers visited a change area one or more times in a trial even when the change went undetected. While this might be indicative of implicit change detection, undetected visitations in AOI 1 were not sufficiently different from baseline visitation and this conclusion cannot be drawn at this time.

As was just noted, both young and old adults visit areas more than once when they correctly identify change. It would be interesting to determine why change would not be detected within a single visit to the change area. Figure 24 below compares eye movement behaviors when the eyes land on the change

(i.e., AOI 1) more than once. The left panel shows the number of fixations cumulated on the change area before and at detection; the right panel shows the average duration of fixations in the change area before change is detected and on the final visit, when change was successfully detected.

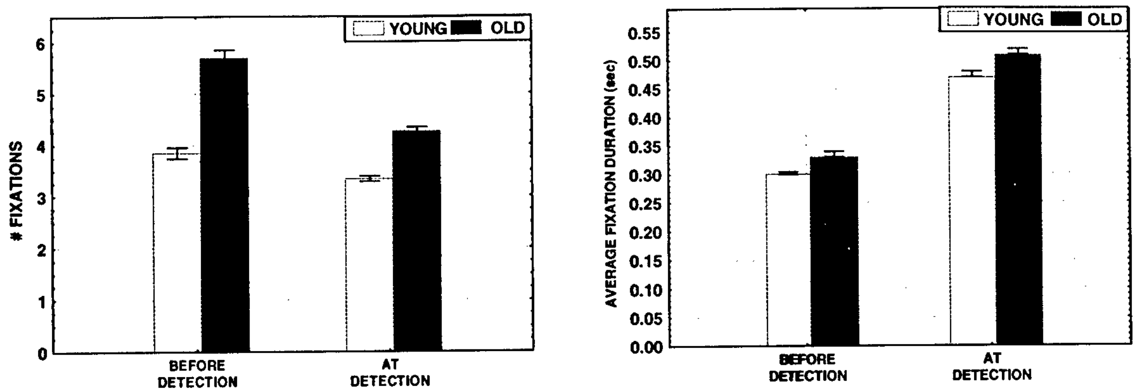

Figure 24. Comparison of dwells before detection with the final dwell at detection as a function of the total number of fixations within a dwell (left) and the average fixation duration within a dwell (right).

As shown in Figure 24 (left panel), it is not for a lack of fixating the area that change is not detected on the first few visits. Observers seem to have amply fixated the area (approximately 4 or more fixations). The answer seems to lie in the amount of time spent fixating the change (on average, right panel). The average duration of fixations in the change area before change was detected was rather brief (300-330ms), which was roughly comparable to durations in the unchanging area of the scene (AOI 3). The dwell in which the change was detected, by contrast, was much longer [470-510ms; $F(1,117)=709.51$, $p<0.001$]. This seems to suggest that a minimum amount of time must be spent on the change area in order for it to be detected or confirmed. In light of the implementation of the change blindness paradigm, this minimum amount of time for a single fixation might be estimated at 280ms. This number is estimated from a minimum amount of processing on the initial presentation of the scene (100ms), the intervening blank screen (80ms) and a minimum amount of processing on the changed scene (100ms). The observed values of fixation durations on AOI 1, ranging from 420 – 510ms, were well above this estimate of minimum processing time (i.e., 280ms), but also below 580ms, which would correspond to the maximum available time of each scene and the blank screen (250ms + 250ms + 80ms = 580ms).

Given the importance of viewing time in change detection, the relationship between the average time spent in the change area (AOI 1) and the probability of detecting a change was calculated (collapsing across changes). The resulting functions for young and old adults are provided in Figure 25 below. Recall that dwells are accumulated consecutive fixations within a region, specifically AOI 1.

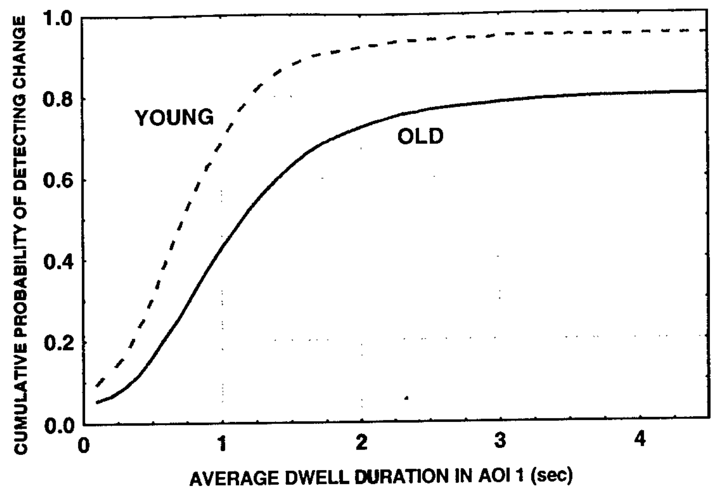

Figure 25. Cumulative probability of detecting change as a function of average dwell duration in AOI 1.

The cumulative probability of detecting a change, as shown in Figure 25, increases (nonlinearly) with increases in average dwell duration, until it reaches asymptote (note that variance across data points on the curves correspond to the variance between subjects). In general, the longer one dwells within the change area, the more likely it is that change will be detected. Dwells longer than approximately 2 seconds for young adults and 3 seconds for old adults show minimal benefits for improving the likelihood of detecting change. The increases in average viewing time in AOI 1 increases the likelihood of detecting a change for both young and old adults, although young adults show a benefit with shorter durations than older adults. The asymptote at 0.95 for young adults and 0.80 for old adults suggests that a sufficiently long dwell in the change region would most likely result in successful change detection (>80%). Hence, viewing duration in the change region seems to be important for successful detection of change.

Discussion

The goals of Experiment 2 were to examine the roles of intrinsic abilities and extrinsic factors on perceptual change detection and to determine if explicit and implicit change detection would be reflected in eye movement behaviors. Overall, the results support three general conclusions. First, of the intrinsic constructs examined (i.e., attention, working memory, inhibition and perceptual speed), change detection latency was predominantly mediated by attentional and visuo-spatial working memory abilities. Also, change detection was influenced by extrinsic factors to varying degrees, with change salience having the largest effect, followed by change meaningfulness. The manipulation of the relevance of the context did not have much of a discernable influence on overall change detection performance. Finally, eye movement measures of change detection revealed that the number of fixations prior to reaching a changed area may not be as important to the successful explicit detection of the change as the average gaze duration. Moreover, these measures elucidated the nature of the effects between meaning, age and salience, indicating

that older adults may be initially sensitive to meaning under conditions of low salience (i.e., elapsed time, elapsed number of fixations to first entry into change area). Finally, the evidence did not suggest that observers implicitly maintained a representation for change without their awareness (i.e., average duration and percent fixations on miss trials); however, both young and old adults appeared to be fixate the change area (i.e., they had at least 1 entry to the change area) even though they did not explicitly detect it (i.e., miss trials). Each of these findings is discussed in the sections that follow.

Attention Is One Of Several Mediators In Change Detection Performance

Specifically, it was hypothesized that attention would play a role in perceptual change detection, along with working memory, perceptual speed and inhibitory abilities. The present research not only establishes a solid link between change detection and attention, defined by the eccentricity at which observers achieved 50% accuracy on the FFOV task (as implied by Rensink et al., 1997, among others), but it establishes the relative weight of that link in light of other mediators in change detection latency. In fact, attention was not the strongest factor accounting for change detection response time; rather it was secondary to visuo-spatial working memory. The contribution of perceptual speed was small, but significant. Taken together, the results suggest that not only is change detection influenced by the number of attentional samples required to scan the scene, which was supported by eye movement analyses, but it also influenced by representation of what was sampled, specifically, the object-spatial properties of the sample.

It should be noted that attention and visuo-spatial working memory were difficult to distinguish. The strong shared variance between attention and visuo-spatial WM may be related to the spatial components of the tasks underlying these factors. Recall that the FFOV is a measure of the ability to localize oblique targets in the periphery (subjects had to remember where to point and click on the spokes of the wheel after seeing the 250ms stimulus). The visuo-spatial working memory (VSWM) tasks assess the ability to remember and manipulate objects, their features and spatial locations (e.g., remembering the cards turned over and where they were located in the "concentration" game or reproducing complex shapes and their locations after seeing them for 10 seconds). Thus, the shared variance between attention and VSWM correspond to the spatial orienting to a (simple or complex) target and remembering its location. Spatial orienting and remembering is required of both the FFOV and the VSWM tasks, but not other tasks, such as verbal WM tasks. Accordingly, the variance explained by the VSWM alone may be for objects. Although the FFOV task also has objects, perhaps they are too simple to account for as much of the change detection variance as the VSWM tasks, which have objects that are more complex. The independent account of attention may be for the selective attention (discriminating oblique targets from vertical distractors). This alternative can be examined in the data, although the distinction between tasks that focus on spatial relations from tasks that require remembering objects independently of their locations is problematic.

Instead, a slightly clearer distinction was made between tasks that were "more visual object/less spatial" and those that were "more spatial/less visual". An analysis conducted post-hoc supports that the two dimensions of tasks do slightly differ in the amount of variance that they share with attention (i.e., FFOV) in accounting for RT. The tasks that were "more visual object/less spatial" share 52% of the variance accounted for in RT with attention while tasks that were "more spatial/less visual" shared 61% of the variance accounted for in RT with FFOV. While this result supports the idea that the shared variance between attention and VSWM corresponded to the spatial orienting to an object and remembering its location, further investigation will be needed before drawing a strong conclusion.

It was somewhat surprising that some of the other constructs did not play a more vital role in change detection performance. The lack of support for perceptual speed was unexpected in light of research by Salthouse and colleagues (1988, 1992). Yet, perhaps perceptual speed should not account for all age-related variance found in complex task performance. If we consider the fact that age differences are not eliminated by providing additional time to perform some tasks (Storandt, 1977; this is also likely of the current change detection task), then the lack of a finding here is not so surprising.

Another finding was that proactive interference measures did not account for any variance in perceptual change detection performance. One explanation might be the non-repeating nature of the pictures. The pictures were contextually similar, but they were not identical. Likewise, the changes were as unique as possible. Thus, PI might only buildup when subjects are repeatedly exposed to the stimuli (as in Flicker et al., 1990). Another explanation might be that the analysis was not sensitive enough to uncover the effect of PI buildup. In other words, PI buildup might occur, but it might serve to impair recognition memory rather than slow RTs (or increase false alarms, as mentioned in the footnote). Perhaps alternative measures of PI buildup may serve to uncover such an effect on change detection performance.

The link between visuo-spatial WM and change detection performance is consistent with other findings in the literature that suggest memory plays a role in perceptual change detection. For example, observers may fail to retain identity information about an object, despite having successfully attended to it previously, resulting in the failure to detect a change in the object (e.g., Becker, Pashler & Anstis, 2000). Furthermore, the results presented here are consistent with the notion that memory for scenes is not detailed (e.g., McConkie & Currie, 1995; Irwin & Gordon, 1998; Henderson & Hollingworth, 1999b; Currie et al., in press). Specifically, the repeated entries to the change area suggested that the memory for objects and locations previously examined was not sufficient for the observer to detect the change. The constraint in memory may be related to 3-4 "object files" (the capacity limit of successful change detection across a saccade; Irwin, 1996), to the saccade target location (e.g., Irwin & Gordon, 1998; Currie et al., in press), or processing time on the item undergoing change (as found in this study, a minimum fixation duration was necessary for successful change detection).

Yet, visuo-spatial WM alone was not the only factor that contributed to perceptual change detection. The results of this study suggest that the contributions of attention and visuo-spatial WM, along with perceptual speed, are useful in accounting for individual differences in change detection latency. Moreover, these same factors (visuo-spatial WM, attention and perceptual speed) explained age-related variance in perceptual change detection. That is, the older adults' declines in visuo-spatial WM capacity, smaller attentional breadth and slower perceptual speed were linked to the latencies in detecting changes in scenes. The idea that multiple factors are involved in change detection has been suggested in the literature. For example, Simons and Levin (1997) suggested that attention may be necessary but not sufficient for successful change detection; however, alternative factors were not proposed. The current study examined multiple factors, not all of which were successful in explaining the time to detect changes in scenes, but 3 factors in particular provided the best explanation of differences in time to detect changes in scenes. The results clarify the role of the factors involved in change detection, and their relative contributions.

Scene Context and the Detection of Meaningful Changes

It was hypothesized that detection of meaningful changes would be affected by age and salience. Indeed, this was found in the results, however the explicit response time data and the eye movement data need to be considered together in interpreting the relationship. Considering only the explicit response time data, older adults may be portrayed as insensitive to meaning when the change was also of low salience; however, eye movement measures modified the interpretation of these effects by showing that older adults were sensitive to high meaning in low salience changes (i.e., fewer fixations and less time). It is likely that the early fixations were not sufficiently long to detect the change, given the finding that fixation duration was more important for change detection than number of fixations. Hence, the initial effect (that older adults are sensitive to meaning under low salience conditions) was lost over the course of the trial because the older adults took longer to process information about the change and the initial glance at the change area was too brief. Taken together, the old adults explicitly responded to the change a considerable amount of time later than the young adults, particularly when low salience change was meaningful.

It was also hypothesized that detection of meaningful changes would be enhanced by increasing scene context (via motion and sound). While the movie condition was successful in creating a subjectively realistic driving context, it did not influence performance as strongly as it could have. It may be that in order to observe scene context effects, the change detection task must be of secondary importance to another relevant, ongoing task and the changes must occur concurrently with the dynamic context. These treatments set the current manipulation of scene meaningfulness apart from the approaches of Wallis and Bulthoff (1997) and Hayhoe et al., (1998). In both instances of the latter approaches, the primary task of the participants was *not* change detection. It was driving in one case (Wallis & Bulthoff, 1997) and block-copying in the other (Hayhoe et al., 1998). However, this account is complicated by the finding that passive

viewers in the driving task were able to detect more changes overall than the active drivers, relevant or not (Wallis & Bulthoff, 1997). It is important to note that unique in the current approach was that the context of the scene was ongoing with the change detection task. In other words, the context built up by the movie preview might have been disrupted with the onset of the flickering change while the primary tasks in the other literature continued as the observers looked for change. For example, participants continued to drive as they looked for changes in obstacles (Wallis & Bulthoff, 1997).

Other methodological approaches might have independently or collectively contributed to this result. For example, the duration of the movie might not be sufficiently long to produce robust effects or perhaps the second fixation mark was too disruptive and did not allow the momentum of the movies to continue into the flicker sequence, even for a short period. It is also possible that the measure of overt response to the change was not sensitive enough to detect the effect of scene meaningfulness.

Finally, the definition of high and low meaningfulness might also be a source for the attenuated meaning effect. Although several attempts were made at defining meaningful items and changes in scenes, perhaps subjective ratings of meaningfulness do not correspond to what is actually relevant in a task or people are not fully aware of what is meaningful in a task (when they are not performing it directly).

In sum, while the movie condition was reported to be more realistic and meaningful, it was not meaningful enough to produce consistent trends in the data. Several explanations for this result have been proposed and provide topics for future investigation.

Eye Movement Behaviors Reveal Explicit Change Detection

Eye movement behaviors were useful in revealing age differences (and similarities) in the search and representation of these complex, realistic scenes. It was observed that when nothing in the scene changed, older and younger adults showed similar patterns of viewing the scene (i.e., average fixation duration and the percent of fixations landing in each region of the display). However, prior to landing on the change (when change was present), the older adults made shorter saccades, took longer and fixated more frequently, which was reflective of their smaller FFOVs and declined visuo-spatial working memory abilities. The finding that FFOV size determines number of fixations and consequently affects search RT is consistent with previous findings with simple stimuli (Scialfa et al., 1994); however, the results of this study suggest that the decline in visuo-spatial working memory abilities may be a better determinant of frequency of viewing and its impact on search RT.

Moreover, increased processing at the site of the change seemed to be a useful indication of the explicit detection of change. Previous studies have shown that the saccade target is an important component of change detection (McConkie & Currie, 1996; Currie et al., in press; Henderson and Hollingworth, 1999b), but the relevance of processing time (i.e., fixation duration) has been somewhat overlooked. Increased processing was suggested by the higher percentage and longer average duration of

gazes in the change area relative to the same area when it was not changing, especially for older adults. Age differences emerged in eye movement measures of change detection, as older adults seemed to look longer before detecting change.

GENERAL DISCUSSION AND CONCLUSIONS

The overriding goal of Experiments 1 and 2 was to investigate the roles of scene characteristics, memory and attentional breadth on the representation of complex real-world scenes. The first experiment investigated the role of attentional breadth in change detection latency as a means of testing the assumption that changes in scenes are detected by sequentially sampling portions of the scenes with an attentional window (as in Rensink et al., 1997). A negative correlation observed between change detection latency and a measure of attentional breadth (FFOV) suggested that subjects with broader attentional windows were able to detect changes with fewer samples. Experiment 1 also showed that factors shown influencing attentional control (i.e., salience, meaning and eccentricity of changes) also influenced perceptual change detection performance.

Because attention may be necessary but not sufficient for change detection (i.e., Levin & Simons, 1997), Experiment 2 examined the roles of working memory, inhibition and perceptual speed abilities in addition to attention in perceptual change detection performance. It was demonstrated that attention and visuo-spatial working memory were primarily related to change detection latency, with perceptual speed playing a small but significant role. Furthermore, these factors accounted for age-related variance in change detection. The effect of change meaningfulness on response time and accuracy performance was moderated by change salience and the age of the observer, such that older adults did not show a meaningfulness benefit when the change was of low salience; however eye movement data revealed that older adults were indeed initially sensitive to meaning of low salience changes. The effect of meaningfulness on change detection did not seem to be influenced by increased engagement in the scenes.

Experiment 2 also showed that observers looked more frequently and looked longer at areas undergoing change, relative to the same area when it was not undergoing change. Additionally, Experiment 2 showed that attentional breadth (i.e., FFOV) and visuo-spatial WM ability corresponded with two measures of eye movement behaviors, saccadic amplitude and the number of dwells in the scene. Individuals with larger FFOVs were able to make longer saccades and fewer dwells in the scene than those with smaller FFOVs, supporting the finding in Experiment 1 that broader attentional windows related to change detection latency; however, visuo-spatial working memory was more strongly associated with the number of dwells in the scene. This reinforces the claim that not only is change detection influenced by the number of attentional samples required to scan the scene, but it also influenced by the memory (i.e., representation) of what was sampled, specifically, the object-spatial properties of the sample.

The cumulative findings suggest that change is difficult to detect, especially for older adults; detection is mediated by the characteristics of the object; and attentional and visuo-spatial working memory abilities contribute to change detection. It was found that younger and older adults do not seem to differ in their initial viewing and processing of scenes but interruptions to the processing of scenes had profound

effects on the ability to represent the scene (and items changed in the scene) and older adults were even more adversely affected by such interruptions. Yet, age differences were mediated by attentional components (i.e., breadth), and visuospatial working memory and so chronological age in and of itself doesn't appear to be a predictor for decrements in performance.

Theoretical Implications

Previous researchers have acknowledged that attention plays a significant role in change detection and scene representation (e.g., Irwin & Gordon, 1998; Rensink et al., 1997), and while some even went so far as to suggest that attention may be "necessary but not sufficient" (Levin & Simons, 1997), the literature has only scratched the surface in providing a complete account of change detection and scene representation.

The present research not only links change detection and attention (as previously implied by the literature), but it establishes the relative weight of that link in light of other mediators in change detection latency. Attention played a role in accounting for change detection response time, secondary to object-spatial working memory. This finding has implications for the typical conclusion drawn in the change detection literature (i.e., that the incomplete representation for the details in complex scenes is due to an attentional constraint in encoding). It is suggested here that at least part of the difficulty in change blindness is linked to a limited retrieval ability.

This finding also goes some way in refuting claims that no internal representation of scenes exists (e.g., Horowitz & Wolfe, 1999), otherwise measures of memory (such as the tasks employed here) would not relate to the speed of searching for and correctly identifying change. The finding that memory is one of several components important for successful change detection suggests that the capacity of visuo-spatial working memory corresponds to the number of objects represented in the scene and their spatial relations. Irwin (1996) suggests that the capacity for details maintained across a single saccade is approximately 3-4 objects and consists of identity and coarse location information. Thus, the greater the number of the objects in the scene represented (associated with greater WM capacity), the greater the likelihood that one of them corresponds to the item undergoing change.

Finally, given the results reported here, one could not conclude that it is always the case in the representation of scenes that WM always plays a stronger role than attention and that inhibition and perceptual speed never play a role. These roles are likely to vary with demands of the task and training on the task. For example, if attentional breadth increases with practice (as observed by Ball et al., 1988), this could result in improved performance in change detection and it would also be interesting to note if it played as important a role in performance as determined in this study.

Applied Relevance

These results have implications for change detection in the real world. Generally, these results are consistent with previous research that suggest if visual processing is interrupted, change may go unnoticed. Seemingly harmless and routine interruptions, such as blank screens (or blinks, saccades as in other studies), can significantly delay the detection of changes to objects in complex, real-world scenes. Similar change blindness effects have been observed in the real world. Simons and Levin (1998) demonstrated that naïve participants often failed to notice when the lost stranger with whom they were speaking was swapped with someone else, after a barrier temporarily occluded the two conversants during which the exchange was skillfully executed. Another example of change blindness has been documented in the cockpit of highly automated aircraft (Sarter & Woods, in press). Pilots sometimes fail to detect and respond to changes in automation configuration, especially when the automation takes an unexpected action or when it fails completely. Coupling this with subjective reports that pilots look where they expect to find changes (Sarter & Woods, 1997), a dangerous pattern emerges. If pilots only look where they expect to expect to find changes, then the potential exists for them to miss valuable information from other sources that may have changed for reasons they couldn't anticipate (e.g., an action has consequences that the pilot doesn't know, or a change was induced by the co-pilots' actions of which the other pilot is unaware).

This research also suggests that meaningfulness is not a prerequisite for detection. Salience appears to be stronger in guiding attention to the area undergoing change. Taken together, a reasonable design goal follows that meaningful changes should be as conspicuous as possible and where possible, should not accompany interruptions such as eye movements or blinks (and especially if they occur outside the forward field of view even when information is available; see Thomas & Wickens, 2000; Wickens, Thomas, Merlo & Hah, 1999).

Furthermore, on the basis of these results, it does not appear that the design goal of incorporating a compelling scene context necessarily results in faster change detection over less compelling displays. Future studies will have to address this issue further, but in the mean time, it would be prudent to weigh the benefit of the increased sense of "presence" on the one hand against the characteristically increased cost of implementation on the other.

Finally, it is important to consider that missing changes, or the failure to detect some changes, may be acceptable in some real-world applications. For example, the failure to detect case changes in letters (e.g., McConkie & Zola, 1979) did not noticeably interrupt the participant's reading and hence might be viewed as an acceptable occurrence of change blindness. In all likelihood, it would be acceptable to miss changes of low meaningfulness or importance.

Limitations of Findings

A few limitations in this study warrant further consideration, as a prudent caution on the conclusions drawn. They include limitations in correlational procedures and the abilities of psychometrics to measure theoretical constructs of interest.

In the first place, the findings suggest that a relationship exists between attention, visuo-spatial working memory and change detection performance. A relationship between working memory and change detection performance does not necessitate the existence of an internal representation of the scene, but it provides an association between the two. It is possible that this relationship is mediated by another factor that was not considered in this study. Together, with converging evidence from experimental research (e.g., Irwin, 1996; Becker et al., 2000), the claim that an internal representation exists is strengthened.

One drawback of the psychometric approach is that the psychometric tasks were assessed on a different day than performance on the perceptual change detection task. Thus, these measures were assumed to be relatively stable over time. Furthermore, it was assumed that an observed decline on a given measure (for example, perceptual speed) had a similar effect on perceptual change detection performance, regardless of whether the decline was gradual or occurred suddenly.

Future Directions

The potential relation between change detection and its real-world consequences is certainly worthy of future research. The domain of driving promises to be an interesting and rewarding area to develop. Previous research has shown that attentional breadth is related to frequency of driving accidents, due to its ability to tap focused, selective and divided attention, skills all utilized in safe driving. It is of interest that these driving situations also require an accurate representation of details and changes in the environment. Furthermore, given that perceptual change detection encompasses aspects of the attentional breadth paradigm and also reflects other higher order processes (visuo-spatial WM), perhaps the study of perceptual change detection has the potential to increase our understanding of accident and driver behavior correlates.

Parasuraman and Nestor (1991) argue that selective attention, and especially the switching of attention to sources of task-relevant information, is critically related to accident risk, particularly in older drivers. It is estimated that 25% - 50% of motor vehicle crashes result from driver inattention (Shinar, 1978) and the failure to make important observations, potentially hazardous to others, has been cited as an undesirable driver behavior, with a slight relation ($p<.11$) to accident involvement when age and driving experience are taken into account (Parker, Reason, Manstead & Stradling, 1995).

Ball et al. (1993) have been successful in finding a correlate of accident involvement. As alluded to previously, they found a correlation of .52 between crash frequency and attentional breadth (i.e., FFOV). In addition, FFOV was similarly predictive (i.e., $r=.45$ to .48) for the following six crash types: (1) failure to notice a traffic control device, (2) failure to notice another vehicle, (3) merging, (4) hitting the rear of

another vehicle, (5) backing up into another vehicle/object, and (6) other. Furthermore, for intersection accidents compared with non-intersection accidents, FFOV predicted 41% and 49% of the variance, respectively. Ball and Owsley (1991; see also Owsley, Ball, Sloane, Roenker & Bruni, 1991) reported that attentional breadth was a stronger predictor of crash frequency than a composite measure of overall mental status score, although they did not evaluate unique contributions within the mental status measure.

These findings are promising, yet further investigation is required before drawing more general conclusions, particularly to an elderly population. The marriage of intrinsic (specifically, attentional breadth and visuo-spatial working memory) and extrinsic (change meaningfulness and salience) factors in the detection of change in real world scenes, as demonstrated here, has the potential to increase our understanding of accident and driver behavior correlates. It is clear that an understanding of factors underlying driver behavior (especially elderly drivers) is a concern for safety and will be important for future study.

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APPENDIX A. FOVEAL SUBTASK PERFORMANCE

Participants were instructed to emphasize accuracy on the foveal task, since they were allowed an unlimited amount of time to respond, and thus, significant results for the accuracy of responding are captured in Figure 26 below. Most prominent is the significant cost for older subjects ($F(1,49) = 16.561$, $p<.001$). Secondly, effects of eccentricity and number of distractors interact, such that increasing eccentricity of the peripheral target improves foveal task performance when distractors are absent, but has no effect when they are present ($F(2,98) = 15.590$, $p<.001$).

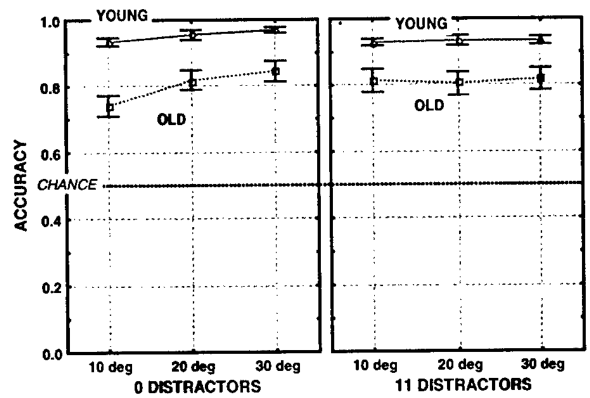

Figure 26. Mean accuracy for the foveal task for the age X eccentricity X #distractors interaction.

Finally, Figure 26 presents the joint effects of age, eccentricity and distractors. The three-way interaction suggests that old age amplifies the effect of the two-way interaction: the cost of decreasing eccentricity when distractors are absent is greater for older than younger adults ($F(2,98) = 5.685$, $p<.005$).

This pattern of accuracy suggests that it may be more difficult (in terms of foveal task performance) to divide attention between the two tasks when a single peripheral target appears near the center (although this is not the case for peripheral task performance, as will be shown later). If subjects only performed the foveal task (disregarding instructions), then another possible explanation is that the focused attention required for the peripheral task is more susceptible to distraction when a single target appears at 10 degrees, than when it is part of the background noise or appears at greater eccentricities.

APPENDIX B. ANOVA RESULTS FOR PERIPHERAL LOCALIZATION TARGET ACCURACY OF THE FFOV TASK.

Conditions	df Effect	MS Effect	df Error	MS Error	F	p-level
Age	1	4.13	49	.07	61.01	.01
Task Type	1	3.59	49	.01	292.01	.01
Target Type	1	5.81	49	.02	314.70	.01
Eccentricity	2	2.58	98	.02	148.04	.01
#Distractors	1	125.95	49	.04	2970.57	.01
Age X Task	1	.20	49	.01	16.56	.01
Age X Target	1	.33	49	.02	17.64	.01
Task X Target	1	.03	49	.01	2.36	.13
Age X Eccentricity	2	.55	98	.02	31.42	.01
Task X Eccentricity	2	.59	98	.01	40.95	.01
Target X Eccentricity	2	.97	98	.01	103.21	.01
Age X Distractors	1	.35	49	.04	8.32	.01
Task X Distractors	1	.01	49	.02	.20	.66
Target X Distractors	1	5.09	49	.03	199.82	.01
Eccentricity X Distractors	2	3.10	98	.06	199.45	.01
Age X Task X Target	1	.03	49	.01	2.59	.11
Age X Task X Eccentricity	2	.01	98	.01	.57	.57
Age X Target X Eccentricity	2	.04	98	.01	4.69	.01
Task X Target X Eccentricity	2	.01	98	.01	.66	.52
Age X Task X Distractors	1	.18	49	.02	11.60	.01
Age X Target X Distractors	1	.46	49	.03	18.20	.01
Task X Target X Distractors	1	.10	49	.01	20.30	.01
Age X Eccentricity X Distractors	2	.51	98	.02	32.59	.01
Task X Eccentricity X Distractors	2	.37	98	.01	41.30	.01
Target X Eccentricity X Distractors	2	.76	98	.01	90.84	.01
Age X Task X Target X Eccentricity	2	.05	98	.01	6.91	.01
Age X Task X Target X Distractors	1	.05	49	.01	9.08	.01
Age X Task X Eccentricity X Distractors	2	.03	98	.01	3.68	.03
Age X Target X Eccentricity X Distractors	2	.10	98	.01	12.17	.01
Task X Target X Eccentricity X Distractors	2	.01	98	.01	2.08	.13
AgeXTaskXTargetXEccentricityXDistractors	2	.03	98	.01	4.56	.01

APPENDIX C. DEMOGRAPHIC INFORMATION.

		YOUNG	OLD
AGE	(years)	*M* = 20.9 *SD* = 3.1	*M* = 68.3 *SD* = 4.2
SEX	Men (n)	19	21
	Women (n)	47	44
VISION	Near	*M* = 20/20.2 *SD* = 1.2	*M* = 20/21.6 *SD* = 3.7
	Far	*M* = 20/20.8 *SD* = 4.0	*M* = 20/22.9 *SD* = 6.1
	Color (% pass) [a]	98.5%	93.8%
EDUCATION	(years)	*M* = 14.9 *SD* = 2.6	*M* = 15.3 *SD* = 3.0
HEALTH STATUS	Participation in fitness activity (%)	88%	92%
	Use of Medications[b] (%)	48%	91%
	Self-perceived health rating (%)		
	Excellent	51%	31%
	Good	47%	66%
	Fair	2%	3%
	Poor	0%	0%
	Self-perceived memory ability rating (%)		
	Excellent	18%	5%
	Good	65%	76%
	Fair	17%	19%
	Poor	0%	0%

[a] 1 young and 4 older adults were later found to have color vision deficiencies; however, their performance on color based tasks (Stroop and change detection) was at least as good, and in some cases better, as their age means and thus their scores remained in the overall data set.

[b] excludes use of psycho-therapeutic and beta-adrenergic antagonist medications

APPENDIX D. ORDER AND DESCRIPTION OF TASKS IN PSYCHOMETRIC SESSION.

	TASK	TASK DESCRIPTON	DEPENDENT MEASURE
1	Near/Far Vision	Assessed visual acuity at distances of 1 and 20 feet.	at least 20/40 near/far vision
2	Ishihara Color Vision Test	Test of color blindness. (Ishihara, 1989)	Pass (>12 plates correctly identified)
3	FFOV Task	Localize 20° oblique target, appearing for 250ms among 11 vertical distractors, at one of three eccentricites (10°, 20°, 30° from center). Control task: localize oblique target without distractors. (modified stimuli from Ball et al., 1988; refer to p.47)	°eccentricity (at 50% accuracy, range 0° - 30°)
4	Pre-Questionnaire	Self-reports of: age, gender, handedness, most recent occupation, overall health and fitness (including use of **medications or drugs), visual function, and memory ability compared with same-age peers.**	
5	Proactive Interference	Recall (i.e., write) a series of 7 stimuli presented on a computer monitor. Stimuli consisted of 3 characters, either all letters or all numbers. All stimuli on the first 4 trials were letters; all stimuli on the last trial were numbers. Before each trial began, a fixation (+) was displayed (1 sec). The 7 stimuli were then presented at a rate of 1/second, followed by a 45 second writing interval during which the word "WRITE" appeared. A 5 sec warning was provided before the next trial automatically began. Participants were instructed to write as many of the stimuli as they could remember. Order of recall was not important, as long as the sequence within a string was correct.. There were a total of 5 trials. (modified from Wickens et al., 1963)	# correctly recalled strings (max = 7 per trial)
6	Box Completion	Create as many boxes (squares) as possible within 30 seconds by drawing the fourth line of an unfinished square. (Salthouse, 1992)	# boxes completed (max = 100)
7	Digit Copying	Copy as many digits (numbers) as possible within 45 seconds. (Salthouse, 1992; Wechsler, 1955)	# digits copied (max = 100)
8	Digit Symbol	Write the symbol corresponding to each number until the time limit expired (60 sec). Each number (1-9) was assigned a unique symbol (a key was always available for reference). (Salthouse, 1992; Wechsler, 1955)	# digits scored (max = 50)
9	Rey-AVLT	Immediately recall a list comprising 15 everyday words. The same list was recalled after an auditory presentation 5 times (trials 1-5), followed by the immediate recall of a novel list (trial 6). The first list was then recalled an additional time without the auditory presentation (trial 7). (Rey, 1964; Lezak, 1995)	# words recalled (max = 15 per trial)
10	Memory Tiles	Find matching tiles in 6x10 grid by flipping over two tiles at a time until all pairs are found. Tiles were initially placed with picture-side down in a random order and participants were allowed to view 2 tiles at a time. If the 2 selected tiles matched, they were removed from the grid. If not, the tiles were returned to picture-side down. Participants continued to flip pairs of tiles until all matches were found and no tiles remained on the grid. Performance was recorded by the number of seconds it took to find all of the matches and by the total number of pairs flipped to find all of the matches. Practice on a 3x3 grid, using different pictures on the tiles, was provided.	# pairs examined (min = 30), time to find all pairs
11	Stroop	Respond to the hue of the letters on the display as quickly and as accurately as possible. An initial fixation (+) appeared for 750ms, which was immediately followed by either a neutral letter string/hue (e.g., **XXXXX**), a	Cost = RT incongruent –

	TASK	TASK DESCRIPTON	DEPENDENT MEASURE
		congruent word/ hue (e.g., **RED** displayed in red) or an incongruent word/ hue (e.g., **RED** displayed in blue). Four responses were possible (red, green, blue, yellow). Word/hue congruency was blocked. Observers had 3 sec to respond to the hue, while ignoring the name of the word. There were 24 practice trials followed by 6 blocks of 24 test trials each (i.e., 2 blocks of each condition). Feedback was provided, but instructions emphasized speed and accuracy. (based on Stroop, 1935)	RT neutral trials (min = 0ms)
12	Card Rotations Test	3 minutes to determine if a series of simple and complex shapes are the same (but rotated) or different (i.e., mirror image). Two trials, 3 minutes each. (Ekstrom, French, Harman, & Dermen, 1987)	# correctly identified shapes each trial (max = 80 each)
13	Maze Tracing	3 minutes to draw a continuous line through a series of short mazes. (Ekstrom et al., 1987)	# completed mazes (max = 24)
14	Sequential Complexity Worksheet	Solve a series of arithmetic problems until 3 min expired. Each equation had 6 single-digit numbers and 5 operands, either addition or subtraction. Each operation had to be solved in sequential order. Solutions (and all intermediate solutions) were always between 1 and 9. (paper and pencil modification of Verhaeghen, Kliegl & Mayr, 1997)	# correct solutions (max = 46)
15	Coordinative Complexity Worksheet	Solve a series of arithmetic problems until 3 min expired. Each equation had 6 single-digit numbers, 5 operands (either addition or subtraction), and brackets or parentheses delineating priority of operations. Equations enclosed by parentheses had to be solved first, followed by equations enclosed by brackets, and then the remaining unenclosed equation could be solved. Solutions (and all intermediate solutions) were always between 1 and 9. (paper and pencil modification of Verhaeghen et al., 1997)	# correct solutions (max = 46)
16	WMS Paragraph Recall	Immediately recall of a story after verbal presentation. 67 words describe a story with a logical progression. Some paraphrasing is allowed (must meet scoring criteria; Wechsler & Stone, 1973). Two stories presented.	average score of both paragraphs (max = 25)
17	Forward & Backward Digit Span	Immediately recall a sequence of numbers in the correct order. Digit sequences progressively lengthened as the participant continued to correctly recall numbers. The forward digit span required subjects to repeat the sequence in the same order as it was presented, while the backward digit span required subjects to repeat the sequence in the reverse order of its presentation. (Wechsler, 1955)	# digits recalled in correct sequence (max = 14 forward, 14 backward)
18	Visual Retention (modified)	Reproduce figural material. After viewing the stimuli for 10 sec, participants had unlimited time to draw all objects and their features in the proper locations (drawing aptitude was irrelevant). Stimuli consisted of simple shapes (i.e., triangles, squares, lines), but they progressively increased in number and complexity. 12 stimuli were presented (modified from Benton, 1963, with more complex combinations of stimuli)	# correctly drawn figures (max = 12); # features missed (min = 0)
19	Verbal Paired Associates	Recall easy and difficult word associations. 8 word pairs were presented at a rate of 1 per 3 sec. Then one word from each pair was presented, and the participant had to recall the word that was associated with it. Feedback was provided each time. Easy word pairs were semantically associated (e.g., fruit & apple), while difficult word pairs were arbitrary (e.g., obey & inch). Participants had 3 attempts to recall all 8 associations. (Wechsler & Stone, 1973)	# of words correctly recalled (max = 12 easy, 12 hard)

APPENDIX E. CHANGE DESCRIPTIONS & CHARACTERISTICS.

	DESCRIPTION	OBJECT Meaning	OBJECT Salience	CHANGE Meaning	CHANGE Salience	ECC	Prior Moving	CHANGE TYPE
1.	Headlights illuminated on taxi, left	LOW	LOW	HIGH	LOW	P	YES	ADD/DELETE
2.	Removed street sign; right	HIGH	HIGH	HIGH	LOW	P	NO	ADD/DELETE
3.	Flipped arrow; center	HIGH	HIGH	HIGH	HIGH	P	NO	LOCATION
4.	Left stoplight changed to red; left	HIGH	HIGH	HIGH	HIGH	P	NO	COLOR
5.	Colors and windows changed black to white; right	LOW	LOW	LOW	LOW	P	NO	COLOR
6.	Closed garage door; center right	LOW	HIGH	LOW	HIGH	P	YES	ADD/DELETE
7.	Moved billboard, center left	LOW	LOW	LOW	LOW	C	NO	LOCATION
8.	Bridge crossbars reversed direction, center	LOW	HIGH	LOW	LOW	C	NO	LOCATION
9.	Car appeared right of center in front of car	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
10.	Tree deleted; right	LOW	LOW	LOW	HIGH	P	NO	ADD/DELETE
11.	Mailbox disappeared; left	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
12.	Jogger moved to center; center left	HIGH	HIGH	HIGH	HIGH	P	YES	LOCATION
13.	Raised roof on right	LOW	LOW	LOW	LOW	P	NO	LOCATION
14.	Changed blue car to white; left	HIGH	LOW	LOW	HIGH	P	YES	COLOR
15.	Two people appeared behind car; right	HIGH	LOW	HIGH	LOW	P	NO	ADD/DELETE
16.	Car approached; right	LOW	HIGH	HIGH	LOW	P	NO	LOCATION
17.	Limo moved; right	HIGH	HIGH	HIGH	LOW	C	YES	LOCATION
18.	McDonald's sign disappeared; right	LOW	HIGH	LOW	LOW	P	NO	ADD/DELETE
19.	83 sign appeared; right	HIGH	LOW	HIGH	HIGH	P	NO	ADD/DELETE
20.	Erased numbers on speed limit; right	HIGH	LOW	HIGH	LOW	P	NO	ADD/DELETE
21.	Rotated arrows on sign; top	HIGH	HIGH	HIGH	HIGH	P	NO	LOCATION
22.	Moved exit ramp; right	HIGH	HIGH	HIGH	LOW	P	NO	LOCATION
23.	Erased wiper; bottom	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
24.	Brake lights illuminated; center right	HIGH	HIGH	HIGH	HIGH	P	YES	ADD/DELETE
25.	Left lane car changes from white to blue; center	HIGH	HIGH	LOW	HIGH	P	YES	COLOR
26.	Arrows moved on sign; left	HIGH	LOW	HIGH	LOW	P	NO	LOCATION
27.	Car appeared in front; left of center	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
28.	White dashed lines turned yellow; center	HIGH	HIGH	HIGH	HIGH	P	NO	COLOR
29.	Van appeared, center	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE

	DESCRIPTION	OBJECT Meaning	OBJECT Salience	CHANGE Meaning	CHANGE Salience	ECC	Prior Moving	CHANGE TYPE
30.	Exit #10 switched; center	HIGH	HIGH	HIGH	HIGH	P	NO	LOCATION
31.	Airplane appeared; right	LOW	HIGH	LOW	HIGH	P	NO	ADD/DELETE
32.	Lane and through switched; center	HIGH	HIGH	HIGH	LOW	P	NO	LOCATION
33.	Car on left moved closer; left	HIGH	HIGH	HIGH	LOW	P	YES	LOCATION
34.	Erased flags on first lightpole; left	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
35.	Cars appeared; center	LOW	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
36.	Deleted van's brake light; right	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
37.	Added sign; left	LOW	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
38.	Deleted 1 spray of water fall; left	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
39.	Raised steeple; center	LOW	HIGH	LOW	LOW	C	NO	LOCATION
40.	Shortened sign; left	LOW	LOW	LOW	LOW	P	NO	LOCATION
41.	Shortened white building; center	HIGH	HIGH	HIGH	LOW	P	NO	LOCATION
42.	Deleted manhole; center	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
43.	Arrow sign flipped, right	HIGH	LOW	HIGH	LOW	P	YES	LOCATION
44.	Stop sign disappears; right	HIGH	LOW	HIGH	LOW	P	NO	ADD/DELETE
45.	Logo changed; top left	LOW	LOW	LOW	HIGH	P	NO	COLOR
46.	Changed stoplight; top center	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
47.	Reverse lights illuminated; center	HIGH	HIGH	HIGH	HIGH	P	YES	ADD/DELETE
48.	Extended left white line dashed to solid; left	HIGH	HIGH	HIGH	HIGH	P	NO	LOCATION
49.	Rotated Home Depot sign, left	LOW	HIGH	LOW	LOW	P	NO	LOCATION
50.	Car appeared opposite lane; left	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
51.	Small building disappeared; right	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
52.	Person moved closer to edge of sidewalk; right	LOW	LOW	HIGH	LOW	P	NO	ADD/DELETE
53.	Stovepipe deleted; top right	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
54.	Erased words on building; left	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
55.	Parked car disappeared; right	LOW	LOW	HIGH	LOW	P	NO	ADD/DELETE
56.	Deleted no turn sign; right center	HIGH	LOW	HIGH	HIGH	P	NO	ADD/DELETE
57.	Raised white crane on building	LOW	HIGH	LOW	LOW	P	NO	LOCATION
58.	Canopy from green to blue; right	LOW	LOW	LOW	HIGH	P	NO	COLOR
59.	Erased white billboard on window; left top	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE

	DESCRIPTION	OBJECT Meaning	OBJECT Salience	CHANGE Meaning	CHANGE Salience	ECC	Prior Moving	CHANGE TYPE
60.	Changed black to green; center	LOW	LOW	HIGH	LOW	P	NO	COLOR
61.	Car changed color; center	HIGH	HIGH	LOW	HIGH	P	YES	COLOR
62.	Erased tree, center	LOW	HIGH	LOW	HIGH	C	NO	ADD/DELETE
63.	Deleted stopsign; left	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
64.	Boat raised; right	LOW	HIGH	LOW	LOW	P	NO	LOCATION
65.	Right car turned green; right	HIGH	HIGH	LOW	HIGH	P	YES	COLOR
66.	Exit barrier moved forward; left	HIGH	LOW	HIGH	LOW	P	NO	LOCATION
67.	Removed shadow; left	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
68.	Green car disappeared; left	LOW	LOW	HIGH	LOW	P	YES	ADD/DELETE
69.	Exit sign moved; left	HIGH	HIGH	LOW	LOW	C	NO	LOCATION
70.	Stoplight disappeared; right	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
71.	Car changed white to yellow; left	HIGH	HIGH	LOW	HIGH	P	YES	COLOR
72.	Guardrail flipped; right	LOW	HIGH	LOW	LOW	P	NO	ADD/DELETE
73.	Train moved closer, left	LOW	HIGH	LOW	HIGH	P	YES	LOCATION
74.	Van changed white to blue; right	LOW	LOW	LOW	HIGH	P	YES	COLOR
75.	Changed shade of grass; left	LOW	LOW	LOW	HIGH	P	NO	COLOR
76.	Man rotated; right	HIGH	LOW	HIGH	HIGH	P	YES	LOCATION
77.	Crosswalk erased; bottom	HIGH	HIGH	HIGH	HIGH	P	NO	ADD/DELETE
78.	Fire hydrant moved forward; left	LOW	LOW	LOW	LOW	P	NO	LOCATION
79.	Lamppost lengthened; left	LOW	LOW	LOW	LOW	P	NO	LOCATION
80.	Changed shade of monument, center	LOW	LOW	LOW	HIGH	C	NO	COLOR
81.	Truck changed red to purple; right	HIGH	HIGH	LOW	HIGH	P	NO	COLOR
82.	Cloud disappeared; center	LOW	LOW	LOW	LOW	C	NO	ADD/DELETE
83.	L sign disappeared; right	LOW	LOW	LOW	LOW	P	NO	ADD/DELETE
84.	Building disappeared; top right	LOW	LOW	LOW	HIGH	P	NO	ADD/DELETE
85.	Man shifted; left	HIGH	HIGH	HIGH	HIGH	P	NO	LOCATION
								Add/Delete: 42
	TOTAL LOW:	44	40	43	44	C: 8	YES: 17	Color: 15
	TOTAL HIGH:	41	45	42	41	P: 77	NO: 69	Location: 28

APPENDIX F. SUBJECT INSTRUCTIONS FOR CHANGE DETECTION TASK

Thank you again for volunteering to be part of this research. Your participation in this experiment will provide a better understanding of the factors contributing to driver awareness in different age groups, and how these factors may ultimately affect driver performance. The Change Detection task is conducted on the first session of the experiment, after you have completed the Driver Questionnaire (if you have not completed the Driver Questionnaire, please tell your experimenter at this time). The purpose of this session is to determine your ability to detect changes in photographs taken from the driver's point of view.

General Procedure

You are going to review pictures of various driving scenes taken from the driver's point of view. Your task is to locate the change in each scene as quickly as possible. The types of picture changes you may encounter include (but are not limited to) the following: changing the color of an object or an area, changing its size, location or orientation, or even deleting or adding an object. You will have up to 1 minute to find the change. If you are unable to find the change within the allotted time, the pictures will stop alternating. The experimenter will not inform you of the correct response. The entire experiment consists of 80 pictures, broken into 4 blocks of 20 pictures each. You will be offered opportunities to take breaks after each set of 20 pictures. You will see five practice pictures before starting the actual experiment. You may repeat the demonstration, if you feel it is necessary.

Flicker Condition

To begin, simply focus on bull's eye in the middle of the screen. The experimenter will then start the trial when your eyes are steadily focused on the bull's eye. Once a trial begins, you will see an image of a driving scene alternating back and forth with a changed image of the same scene. In other words, the same driving scene will be presented but an object or area within the scene will be changing back and forth and may appear to flash. You should press the button as soon as you detect what is changing in the picture. After pressing the button, please describe the change you detected to the experimenter.

Static Condition

To begin, simply focus on bull's eye in the middle of the screen. The experimenter will then start the trial when your eyes are steadily focused on the bull's eye. Once a trial begins, you will see an image of a driving scene displayed for 15 seconds. After 15 seconds, the bull's eye will reappear briefly for you to focus on, and followed by the picture you previously viewed alternating back and forth with a changed image of the same scene. In other words, the same driving scene will be presented but an object or area within the scene will be changing back and forth and may appear to flash. You should press the button as soon as you detect what is changing in the picture. After pressing the button, please describe the change you detected to the experimenter.

Movie Condition

To begin, simply focus on bull's eye in the middle of the screen. The experimenter will then start the trial when your eyes are steadily focused on the bull's eye. Once a trial begins, you will see a movie of a driving sequence displayed for 15 seconds. After 15 seconds, the bull's eye will reappear briefly for you to focus on, and followed by a picture of the last scene in the driving sequence you previously viewed alternating back and forth with a changed image of the same scene. In other words, the same driving scene will be presented but an object or area within the scene will be changing back and forth and may appear to flash. You should press the button as soon as you detect what is changing in the picture. After pressing the button, please describe the change you detected to the experimenter.

APPENDIX G. POST QUESTIONNAIRE.*

1. Please describe your strategy in scanning the scenes and in looking for change: ________________

____

2. While looking for changes, I felt like…

1	2	3	4	5	6	7	N/A
I was in a lab wearing a headband						I was in a car driving through town	

3. How familiar (overall) were you with the scenery in the pictures? Did you recognize the locations?

1	2	3	4	5	6	7	N/A
Not at all Familiar						Very Familiar	

4. How real did the driving scenes seem to you?

1	2	3	4	5	6	7	N/A
Artificial or illusory						Indistinguishable from the real world	

5. To what extent were there times when you felt that you were in a car and you almost forgot about the real world outside?

1	2	3	4	5	6	7	N/A
Never						Almost all the time	

6. What was your overall enjoyment viewing these scenes?

1	2	3	4	5	6	7	N/A
Not at All Enjoyable						Highly Enjoyable	

* Portions of the questionnaire were adapted from Singer & Witmer (1996).

7. To what extent did extraneous events (e.g., wearing the headband) detract from your ability to detect change?

1	2	3	4	5	6	7	N/A
Not at All						Very Much	

8. How high was your self-confidence in your ability to detect change?

1	2	3	4	5	6	7	N/A
Not at All Confident						Extremely Confident	

9. How much did the scene preview influence how you searched for change?

1	2	3	4	5	6	7	N/A
Not at All						Very Much	

10. To what extent did you attempt to look for changes related to driving?

1	2	3	4	5	6	7	N/A
Not at All						Almost all the time	

11. To what extent did you attempt to look for changes that were conspicuous or salient?

1	2	3	4	5	6	7	N/A
Not at All						Almost all the time	

12. Is there anything else you think might be important for us to consider? ______________________

____

APPENDIX H. MEANS AND (STANDARD DEVIATIONS) OF PSYCHOMETRIC TESTS.

COMPOSITE	TASK	YOUNG[a]	OLD[b]	
Attention[c]	FFOV Task (degrees)[c]	26° (7.0)	17° (6.6)	F(1,128) = 63.18 p<.01
Perceptual Speed[c]	Box Completion (# completed)[c]	58 (13.4)	48 (11.4)	F(1,128) = 22.61 p<.01
	Digit Copying (# completed)[c]	82 (11.0)	69 (14.3)	F(1,128) = 31.70 p<.01
	Digit Symbol (# completed)[c]	48 (8.0)	37 (6.7)	F(1,128) = 67.59 p<.01
Visuo-spatial WM[c]	Visual Retention (# pictures incorrect)[d]	3.8 (2.0)	7.1 (1.9)	F(1,128) = 98.17 p<.01
	Visual Retention (# features incorrect)[d]	5.8 (3.9)	13.0 (4.3)	F(1,128) = 98.46 p<.01
	Memory Tiles (RT)[d]	241s (63)	601s (298)	F(1,128) = 92.30 p<.01
	Memory Tiles (Pairs)[d]	102 (27)	152 (44)	F(1,128) = 60.59 p<.01
	Card Rotations Test (% Completion)[c]	75% (15%)	53% (16%)	F(1,128) = 63.58 p<.01
	Card Rotations Test (% Correct)[c]	67% (18%)	40% (17%)	F(1,128) = 78.59 p<.01
	Maze Tracing (# completed)[c]	14 (3)	7 (3)	F(1,128)= 207.26 p<.01
Executive Function[c]	Sequential – Coordinative Complexity[d]	2.3 (4.9)	8.7 (5.0)	F(1,128) = 54.62 p<.01
	Backward Digit Span (# correct)[c]	7.9 (2.1)	7.6 (2.2)	F(1,128) = 0.43 p<.58
Verbal WM[c]	Rey-AVLT Learning (Sum of Trials 1 - 5)[c]	58 (7)	52 (11)	F(1,128) = 14.15 p<.01
	Rey-AVLT Retention (Trial 5 - Trial 7)[d]	1.1 (1.4)	1.7 (2.1)	F(1,128) = 4.14 p<.04
	Verbal Paired Associates (# Easy Trials Correct)[c]	11.2 (1.5)	10.8 (1.6)	F(1,128) = 2.52 p<.11
	Verbal Paired Associates (# Hard Trials Correct)[c]	9.6 (1.8)	6.6 (2.5)	F(1,128) = 62.25 p<.01
	WMS Paragraph Recall (total items recalled)[c]	27.4 (6.5)	24.5 (6.8)	F(1,128) = 6.22 p<.01
Inhibition[c]	PI Buildup (1st half – 2nd half)[d]	0.62 (1.6)	0.09 (1.3)	F(1,128) = 4.21 p<.04
	Stroop (Stroop RT Cost)[d]	98ms (89ms)	332ms (210ms)	F(1,128) = 69.08 p<.01
	Rey-AVLT Interference (Trial 1 - Trial 6)[d]	0.70 (2.1)	1.5 (2.6)	F(1,128) = 3.06 p<.08

[a] n = 66. [b] n = 65. [c] lower numbers indicate poorer performance. [d] higher numbers indicate poorer performance.

APPENDIX I. ANOVA RESULTS.

Accuracy for Change Characteristics

	df Effect	MS Effect	df Error	MS Error	F	p-level
Age	1	2.884265	125	.015139	190.5142	.000000
Preview	2	.005129	125	.015139	.3388	.713288
Meaning	1	.133732	125	.004309	31.0333	.000000
Salience	1	.992678	125	.005108	194.3468	.000000
Age X Preview	2	.001880	125	.015139	.1242	.883346
Age X Meaning	1	.017793	125	.004309	4.1290	.044272
Preview X Meaning	2	.006538	125	.004309	1.5171	.223353
Age X Salience	1	.179755	125	.005108	35.1924	.000000
Preview X Salience	2	.002063	125	.005108	.4038	.668646
Meaning X Salience	1	.141350	125	.004170	33.8950	.000000
Age X Preview X Meaning	2	.010007	125	.004309	2.3223	.102266
Age X Preview X Salience	2	.003298	125	.005108	.6457	.526046
Age X Meaning X Salience	1	.113233	125	.004170	27.1528	.000001
Preview X Meaning X Salience	2	.007509	125	.004170	1.8006	.169458
Age X Preview X Meaning X Salience	2	.001088	125	.004170	.2610	.770706

RT for Change Characteristics

	df Effect	MS Effect	df Error	MS Error	F	p-level
Age	1	4681.720	125	24.50800	191.0282	.000000
Preview	2	39.156	125	24.50800	1.5977	.206473
Meaning	1	469.407	125	10.48136	44.7849	.000000
Salience	1	3910.883	125	6.71392	582.5037	.000000
Age X Preview	2	8.262	125	24.50800	.3371	.714488
Age X Meaning	1	61.512	125	10.48136	5.8687	.016847
Preview X Meaning	2	.422	125	10.48136	.0402	.960568
Age X Salience	1	4.881	125	6.71392	.7270	.395498
Preview X Salience	2	12.985	125	6.71392	1.9341	.148861
Meaning X Salience	1	148.293	125	7.39743	20.0466	.000017
Age X Preview X Meaning	2	8.696	125	10.48136	.8297	.438573
Age X Preview X Salience	2	2.467	125	6.71392	.3674	.693272
Age X Meaning X Salience	1	45.589	125	7.39743	6.1628	.014373
Preview X Meaning X Salience	2	15.411	125	7.39743	2.0833	.128824
Age X Preview X Meaning X Salience	2	3.710	125	7.39743	.5015	.606816

APPENDIX J. ANOVA TABLE FOR EYE MOVEMENT BEHAVIORS DURING STATIC PREVIEW CONDITION.

		YOUNG	OLD	DF EFFECT	MS EFFECT	DF ERROR	MS ERROR	F	P
Elapsed TIME (sec)	Means	3.99	4.03	1.00	0.00	38.00	0.31	0.00	0.99
	SD	3.27	3.30						
Elapsed FIXATIONS	Means	11.78	12.65	1.00	6.01	38.00	3.39	1.77	0.19
	SD	9.78	10.68						
Elapsed DISTANCE to AOI1 (deg)	Means	17.35	16.33	1.00	9.78	38.00	4.36	2.24	0.14
	SD	9.88	10.09						
AVERAGE SACCADE DISTANCE IN AOI3 (deg)	Means	11.29	10.44	1.00	7.28	38.00	2.98	2.44	0.13
	SD	2.46	2.41						
TOTAL FIXATIONS AOI1	Means	2.35	2.41	1.00	0.04	38.00	0.10	0.37	0.54
	SD	2.96	2.96						
TOTAL FIXATIONS AOI2	Means	2.98	3.28	1*	.95*	38*	.20*	4.79*	.03*
	SD	2.81	3.05						
TOTAL FIXATIONS AOI3	Means	39.63	41.75	1*	49.30*	38*	6.50*	7.59*	.01*
	SD	6.23	5.98						
% FIXATIONS AOI1	Means	5.25	5.08	1.00	0.32	38.00	0.32	1.02	0.32
	SD	6.62	6.17						
% FIXATIONS AOI2	Means	6.63	6.89	1.00	0.73	38.00	0.47	1.56	0.22
	SD	6.24	6.34						
% FIXATIONS AOI3	Means	88.12	88.03	1.00	0.08	38.00	0.92	0.09	0.76
	SD	9.80	9.57						
TOTAL DURATION AOI1	Means	0.61	0.59	1.00	0.00	38.00	0.01	0.16	0.70
	SD	0.80	0.75						
TOTAL DURATION AOI2	Means	0.69	0.76	1*	.06*	38*	.01*	6.54*	.01*
	SD	0.71	0.75						
TOTAL DURATION AOI3	Means	9.26	9.59	1.00	1.07	38.00	0.38	2.84	0.10
	SD	1.51	1.35						
AVG DURATION AOI1	Means	0.18	0.18	1.00	0.00	38.00	0.00	0.05	0.83
	SD	0.17	0.14						
AVG DURATION AOI2	Means	0.19	0.19	1.00	0.00	38.00	0.00	0.37	0.55
	SD	0.11	0.11						
AVG DURATION AOI3	Means	0.24	0.23	1.00	0.00	38.00	0.00	0.45	0.51
	SD	0.04	0.03						
% DURATION AOI1	Means	5.71	5.40	1.00	0.94	38.00	0.39	2.40	0.13
	SD	7.40	6.74						
% DURATION AOI2	Means	6.49	6.93	1*	2.15*	38*	.48*	4.49*	.04*
	SD	6.64	6.80						
% DURATION AOI3	Means	87.80	87.66	1.00	0.25	38.00	0.97	0.25	0.62
	SD	10.44	10.17						
TOTAL DWELL AOI1	Means	1.40	1.41	1.00	0.00	38.00	0.03	0.03	0.85
	SD	1.44	1.40						
TOTAL DWELL AOI2	Means	2.06	2.19	1.00	0.17	38.00	0.05	3.18	0.08
	SD	1.68	1.80						
TOTAL DWELL AOI3	Means	3.36	3.40	1.00	0.02	38.00	0.09	0.27	0.61
	SD	1.55	1.64						
AVG DWELL AOI1	Means	0.30	0.30	1.00	0.00	38.00	0.00	0.02	0.90
	SD	0.38	0.33						
AVG DWELL AOI2	Means	0.27	0.29	1.00	0.00	38.00	0.00	2.59	0.12
	SD	0.21	0.22						
AVG DWELL AOI3	Means	3.70	3.84	1.00	0.15	38.00	0.35	0.42	0.52
	SD	2.60	2.64						
# ENTRIES AOI1	Means	1.38	1.38	1.00	0.00	38.00	0.03	0.03	0.87
	SD	1.39	1.37						

* $p<.05$

VITA

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EDUCATION

UNIVERSITY OF ILLINOIS at Urbana-Champaign, Urbana-Champaign, Illinois.
Ph.D. Engineering Psychology expected October 2000. Dissertation Title: *The roles of scene characteristics, memory and attentional breadth on the representation of complex real-world scenes.*
Major Areas: Industrial Engineering and Cognitive Psychology

UNIVERSITY OF ILLINOIS at Urbana-Champaign, Urbana-Champaign, Illinois.
A.M. Engineering Psychology received October 1992. Thesis: *Dual-task training strategies and aging.*

U.S. AIR FORCE ACADEMY, Colorado Springs, CO.
B.A. Human Factors received May 1991.

EXPERIENCE

University of Illinois at Urbana-Champaign, Urbana-Champaign, Illinois
Graduate Student; advisor: Dr. Arthur F. Kramer — *July 1997 - present*
Human Perception and Performance

- Examining the role of intrinsic and extrinsic factors in perceptual change detection performance. A correlational approach is used to investigate the role of intrinsic factors (i.e., attention, memory, perceptual speed), while experimental approach assesses extrinsic factors (i.e., context relevance and salience). Eye movement behaviors examine the representation of change with and without explicit awareness (with Dr. Arthur F. Kramer and Dr. David E. Irwin).
- Supervised the activities of undergraduate research assistants and coordinated weekly meetings.
- Aided in the collection and analysis of data from a study evaluating the effectiveness of the electronic map presentation and terrain depiction (with Dr. Christopher D. Wickens).
- Participated in a research project aimed at investigating techniques employed in learning complex stimuli (i.e., aircraft silhouettes). Determined individual learning strategies and how the structure of training programs could enrich these strategies (with Dr. Stephanie Doane).
- Conducted a meta-analysis on issues associated with reliability and trust calibration. Examined how displays might remedy user miscalibration to multiple sources of information of varying degrees of reliability (with Dr. Christopher D. Wickens).

United States Air Force Academy, Colorado Springs, Colorado
Assistant Professor/Personnel Officer, Behavioral Sciences & Leadership Dept *June 1995 to July 1997*

- Taught introductory psychology and advanced Engineering Psychology, which entailed writing course syllabi, teaching (i.e., lecturing) students, writing and grading exams, and assigning final grades.
- Managed personnel gains, losses and promotions within the Department of Behavioral Sciences and Leadership. Responsible for requisitioning new personnel, preparing performance reports for academic and military promotion boards and supporting reassignment activities.

Hanscom Air Force Base, Bedford, Massachusetts
Executive Officer, 66th Air Base Wing *June 1994 to June 1995*
Operations & Control Integration Manager, Joint STARS Program *August 1992 to June 1994*

- Supervised the development and design of the operator console for the Joint Surveillance Target Attack Radar System (JSTARS). Examined performance issues involved in design of error messaging, display symbology and the location of the symbology. Determined the information requirements for various tasks performed by the operators surveilling ground and airborn units and examined methods for conveying information to support situation awareness.
- Managed the activities of the base wing commander associated with directing base-level support functions (e.g., civil engineering, supply, logistics, and recreation). Supervised staff of 4 personnel.

PUBLICATIONS

Pringle, H.L., Irwin, D.E., Kramer, A.F., & Atchley, P. (in press). The role of attentional breadth in perceptual change detection. Psychonomic Bulletin & Review.

Pringle, H.L., Wickens, C.D., & Ververs, P.M. (1998). Constraints on electronic map presentation and terrain depiction for air-ground targeting: The three map problem. University of Illinois Institute of Aviation Technical Report (ARL-98-3/NAWC-ONR-98-1). Savoy, IL, Aviation Research Lab.

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PRESENTATIONS

Pringle. H.L., Kramer, A.F. & Irwin, D.E. (2000). Factors involved in perceptual change detection. Paper presented at ARL Federated Laboratory 4th Annual Symposium, 21-23 March, College Park, MD.

Pringle. H.L., Kramer, A.F. & Irwin, D.E. (2000). Eye movements, age and the representation of complex real-world scenes. Paper presented at 5th International Conferencer on Human Interaction with Complex Systems, 1-2 May, Champaign-Urbana, IL.

Pringle, H.L., Kramer, A.F., Irwin, D.E., & Atchley, P. (1999). Breadth of attention and change detection. Poster presented at 3rd Annual Vision Research Conference, 7-8 May, Ft. Lauderdale, FL.